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SOIL SCIENCE

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INFLUENCE OF SOIL HYDROGEN-ION CONCENTRATIONS ON INFECTION BY *HETERODERA RADICICOLA* (GREEFF) MÜLLER[1]

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Observational evidence would appear to indicate for the root knot nematode, *Heterodera radicicola*, a tolerance to a rather wide range of soil reactions. The senior writer's personal observations in Florida, for example, have shown root knot to occur both in the rather alkaline soils overlying coral in the vicinity of Miami and in the acid pine flats in the interior of the state. In pineapple fields in Hawaii, likewise, root knot is known to occur in fields that are distinctly acid as well as in those that are on the alkaline side of the neutral point. No exact information as to hydrogen-ion concentration relations appears to be available, however. In an effort to obtain facts as to the influence of measured ranges of soil pH on infection, certain experiments were conducted at this station and the results are reported herein.

LITERATURE REVIEW

The general literature on hydrogen-ion concentration is tremendous. One has only to refer to Clark's (6) book on the subject to realize the complete impracticability of mentioning even the more important contributions in such a paper as this one. There is, likewise, an extensive literature on the more restricted field of effect of soil hydrogen-ion concentration on the growth of plants. Two recent papers that have come to our attention may justify mention in this connection. Wiggin and Gourley (13) in their work on the reaction of greenhouse soils to the growth of plants first review very beiefly a number of papers on soil pH in relation to plant growth and then give the results of their own investigations on greenhouse

[1] Published with the approval of the Director as Technical Paper No. 55 of the Experiment Station of the Association of Hawaiian Pineapple Canners, University of Hawaii.

[2] Nematologist and associate nematologist respectively. The studies herein reported were made possible only by the full coöperation of several others of the technical staff of this station whose assistance is hereby gratefully asknowledged. The first study, for example, was conducted with soils with controlled range of hydrogen-ion concentrations prepared by Dr. C. P. Sideris of the physiology department. The second study was materially assisted at the start in the matter of collection of field soils by Mr. F. A. E. Abel of the chemistry and soils department. The coöperation of field managers of various sugar and pineapple plantations was likewise indispensable in this. Soil pH determinations were made through the courtesy of Dr. F. E. Hance of the Hawaiian Sugar Planters' Association, Experiment Station and Dr. O. C. Magistad of this station, most of them by the latter. Routine examinations of plants as to root knot infection were made by Miss Juliette Oliveira and Miss Erna B. H. Gittel of the nematology Department.

ornamentals. Wessels (12) deals in a similar way with various vegetables grown on Long Island. Much work has been done on the influence of soil pH on various organisms. Dr. Chapman (5) refers to several papers on the subject. Arrhenius (1) shows by experimentation that soil pH plays a very important part in the occurrence of two species of earthworms in the soil. Their activity is apparently limited to a very narrow range in neutral or slightly acid soil. A number of investigations have been conducted on infection of various plants by the root parasitizing fungi. Without attempting an exhaustive literature review, one paper alone, by Burkholder (2) on dry root rot of bean caused by *Fusarium martii* var. *phaseoli* Burk. is cited. In this instance the fungus was tolerant to as wide a pH range as the host plant would endure and root rot occurred throughout the range (pH 4.04 to 8.43).

The literature on effect of soil pH on nematodes is more limited. Chandler (3) states in general that the population of soil nematodes (species not specified) is greatly increased in soil of high acidity (pH 5.2 to pH 6.0). Chandler (4) in his book on parasitology does not mention the possible influence of soil reaction on survival of nematode parasites in the soil. Definite investigations have been conducted on the influence of soil pH on the sugar beet nematode *Heterodera schachtii*. Peters (10) goes into great detail in an exposition of methods of determining soil hydrogen-ion concentrations and of the "pH" method of recording them. He then gives the results of measurements of soil pH in a series of nine plots and of an attempt to correlate these readings with *H. schachtii* cyst counts in the same areas. He does not actually work out the coefficient of correlation between the two variables, but shows in tabular form a sort of rank-order correlation. The hydrogen-ion concentrations determined in his test were from pH 6.0 to pH 6.7, a range of only 0.7 pH. He says, "From the table of averages it is clear that no very exact relationship obtains between the pH of the soil solutions and the cyst concentrations." However, he concludes that "—samples, from an experimental field at Kirton show an indubitable correlation between pH and cyst concentration. The cysts are very numerous in samples giving solutions of pH: 6.0; and few in samples giving solutions of pH: 6.7. Miscellaneous samples from South Lincolnshire in part confirm this correlation; but in a few cases a reverse correlation obtains." Again, "Were this advice followed (liming of sour soils) it is probable that the prevalence of *H. schachtii* would be greatly reduced—at least so far as concerns the strain found on potatoes."

Smith (11) likewise reports on *H. schachtii* in potatoes in another part of England and details an attempt to determine the presence or absence of a definite correlation between soil pH and cyst count. In one field of peat soil there appeared to be "a general trend indicating a negative correlation between pH and cyst count." The figures for pH varied from 4.95 to 6.17, a range of 1.22 pH. A significant correlation of -0.504 was calculated. He points out that there are undoubtedly other factors at play. Smith states in his conclusion, "The pH of 78 samples has been measured electrometrically. When these samples are divided into two groups according to soil type there is found to be a significant negative correlation between pH and cyst counts for 53 peat soils. There is not, however, a significant correlation in the case of the other 25 sandy soils."

The writers have been able to find no other citations referring to specific investigations on the influence of hydrogen-ion concentration of the soil on any phase of nematode biology. Emmert (8, p. 64) in connection with his extensive studies on effects of soil reaction on growth of tomatoes and lettuce, states in a brief paragraph his observation that extremes of acidity and alkalinity appeared to retard nematode development. Need for definite study on possible relationship between soil reaction and amount of soil infestation with *H. radicicola* is clearly indicated.

EXPERIMENTS

By way of preliminary experiment, the same method used by Burkholder (2), that of attempting to adjust soil pH by additions of sulfuric acid and of sodium hydroxide, was employed. The initial pH of a uniform lot of soil was first

taken and then, in different lots, calculated quantities of these two chemicals were added, and the soil was thoroughly mixed and allowed to stand for about a month. At this time hydrogen-ion determinations were made by the quinhydrone electrode method, and a pH range was obtained from pH 3.5 to pH 8.5, with intermediate points as shown in table 1. The soil was placed in root observation boxes (7) and pineapple slips were planted, two to a box, in May, 1928. Roots developed at the outset fairly satisfactorily in all cages, and on June 7, inoculations were made as follows: Suspensions of *H. radicicola* larvae containing approximately 10,000 larvae were poured about the roots of one plant only in a box, and on one side only of the box.

TABLE 1

Effect of differences in initial pH on infection by H. radicicola

NUMBER	pH	H. RADICICOLA INFECTION	CONDITION OF ROOTS
1	3.5	0	Very poor
2	3.5	6	Fair
3-C*	3.5	0	Fair
4	4.5	8	Fair
5-C	4.5	0	Good
6	6.5	8	Poor
7	6.5	8	Poor
8	6.5	10	Poor
9	7.0	10	Fair
10	7.0	10	Poor
11	7.0	10	Fair
12	7.0	10	Fair
13-C	7.0	0	Good
14	8.5	10	Poor
15	8.5	8	Fair
16	8.5	10	Poor
17	8.5	10	Poor
18-C	8.5	0	Good

*C, uninoculated controls.

Observations were made from time to time and it was noted that at least at the intermediate pH values infection took place at once and went through the usual stages of development of new generations and spread from one plant to another until the root systems were pretty generally infected. At the extremes both high and low, of soil pH, root growth was poor but definite infection was noted throughout. Very poor growth occurred at pH 3.5. At 4.5 it was good. At pH 8.5 growth was poor but somewhat better than at 3.5.

On December 19, 1928, about 6 months after inoculation, all plants were removed, the roots washed free of soil, and observations taken on extent of development of root knot. The scale used is an arbitrary one, and is useful only to record relative amounts. It may be considered, however, that the index number 10 means definite, uniform heavy infection and numbers less

than that correspondingly lighter infection. Unfortunately the press of other activities did not permit of checking the pH of the soil, either during the course of growth or at the close of the experiment. The hydrogen-ion concentrations recorded, therefore, are those made at planting time only.

It is obvious that infection occurred throughout the range of initial hydrogen-ion concentrations. If anything, it is more consistently heavy through the middle range, though this may have been due in part to the more consistent availability of susceptible roots.

This experiment, although unsatisfactory as to the reliability of hydrogen-ion concentrations during plant growth, is at least a strong indication that the root knot nematode is tolerant of a wide range of soil reactions.

TEST OF FIELD SOILS OF WIDE pH RANGE

It was well known that the sugar cane and pineapple field sof Hawaii consistently maintain their levels of hydrogen-ion concentration unless specifically treated to bring about a change, and that a very wide range was to be found in different localities. In the higher (mauka) cultivated areas where rainfall is high (up to 150 inches), and the virgin vegetation had been dense, soils occurred with a pH of 4.0 or even lower, while in the lower (makai) sugar cane field levels, especially near ancient coral beds, the pH was often around 8.0.

By consultation with plantation managers, and with the coöperation of their field men, it was possible to locate fields upon which pH readings had been taken from such locations and transported to the Wahiawa Field Station.

It was desired to bring about uniformity as to *H. radicicola* infestation, without too greatly altering the quality of the soils, as often results from heat sterilization. Consequently these soils were spread in thin layers to dry, in a sun exposure. It was known from previous studies (9) that this would bring about complete sterilization in so far as the root knot nematode was concerned.

The dried soils were then tested colorimetrically as to pH by Mr. Abel of this station and samples selected with a desirable range. These were moistened uniformly and placed in the same type of root observation boxes as those used before, there being six boxes for each soil selected. Here they were allowed to stand for 2 weeks when composite samples were made up of about 100 gm. of soil from each of the six boxes, and further pH determinations were made electrometrically at two separate laboratories, by the hydrogen electrode method. The determinations are listed in columns 2 and 3 of table 2. The boxes of each of the selected soils were now divided into two lots of three boxes each. One set was planted to cowpeas the other to pineapples. It should be recognized that the soils for this were collected from a very wide range of locations, consequently they differ widely in soil type and fertility. These differences obviously might be expected to influence plant growth, as they actually did. Records were made of such differences, in some cases photographically, but since they were not sufficient to alter the major conclusions that are justified with regard to the primary consideration, that of influence of soil hydrogen-ion concentration, they are omitted from this report.

Test with Whippoorwill cowpeas

On July 12, 1930, cowpeas were planted in the set of boxes segregated for the purpose. On July 18, after the seeds had germinated, inoculations with *H. radicicola* were made by placing 50 egg masses (potentially about 25,000 larvae) in a horizontal line in the soil on the face of the cage, about 5 inches below the soil surface. Inoculation with egg masses insured that all phases of nematode activity, hatching, migration through the soil, and actual infection of the roots, were subject to the influence of the hydrogen-ion concentration of the soil of the particular root observation box concerned. After the initial readings on soil pH, additional readings were taken at the time indicated in table 2. Such readings are included, as well as results in nematode infection, in the one table.

Preliminary pH readings were taken colorimetrically, mostly in the field, as a guide to selection of soils. The first and second readings here recorded, taken

TABLE 2

Effect of hydrogen-ion concentration on infection in cowpeas by H. radicicola

SOIL NO.	pH DETERMINATIONS					H. RADICICOLA INFECTION 9-18-30		
	Original (6-30-30)		8-4-30	Final 9-18-30	Average pH			
	E-1	E-2				A	B	C
6	4.1	4.1	4.1	4.3	4.2	7	10	10
5	4.4	4.3	4.3	4.2	4.25	10	9	10
2	4.5	4.4	4.4	4.4	4.4	9	8	10
4	4.9	4.7	4.7	4.7	4.7	10	10	9
10	6.1	6.3	6.0	6.2	6.1	10	10	10
1	6.6	6.6	6.4	6.3	6.35	9	10	9
16	7.8	7.8	7.8	7.6	7.7	10	10	7
11	8.0	7.8	7.8	7.7	7.75	9	8	9
14	8.1	8.0	7.9	7.7	7.8	8	8	8

after the soil was dried, constituted a check on a newly installed apparatus in our chemical laboratory. E-1 was an electrometric (hydrogen electrode) determination made, through the courtesy of Dr. F. E. Hance at the Experiment Station of the Hawaiian Sugar Planters' Association, on the soil suspension. E-2 was obtained by Dr. O. C. Magistad at the same time on the thick soil suspension in the A. H. P. C. laboratory with a hydrogen electrode. Subsequent readings were made in the A. H. P. C. laboratory by means of the hydrogen electrode. It is noteworthy that the readings remained fairly constant through the experiment, and that the original order of soils in hydrogen-ion concentration was not changed.

The final determinations of degree of root knot infection were made on the basis of relative values, as before, and can not be interpreted in terms of actual numbers of nematodes penetrating the roots. It was obvious that infection was almost uniformly heavy throughout, and a detailed count was not justified

in that differences would be insignificantly small. There was probably somewhat less infection at the highest pH values, 7.75 and 7.8, though there is no detectable difference between 4.2 and 7.7.

Inspection of the data in the table makes it apparent, without calculating, that the correlation between pH and degree of infection of plants is very low, if indeed not quite zero. This being the case, there can be no particular advantage in knowing the exact figure, as concluded by Smith (11) for his data on sandy soils. In order to make this report complete, however, such correlation was calculated, with 0.25-pH step intervals for the pH and unit index numbers for degree of nematode infection, and found to be -0.325 ± 0.115, a very low negative correlation, and an insignificant one, from the statistical point of view.

TABLE 3

Influence of hydrogen-ion concentration of soil on H. radicicola infection in pineapple

SOIL NO.	pH DETERMINATIONS		H. RADICICOLA (PER CENT ROOT INFECTION)		
	Original (8–14–30)	Final (12–12–30)	D	E	F
6	4.1	4.0	90	96	97
5	4.2	4.2	48	48	85
2	4.3	4.3	91	97	97
4	4.7	4.7	75	59	73
10	6.3	5.9	88	67	90
1	6.4	6.3	74	98	88
16	7.6	7.5	58	60	55
11	7.7	7.7	94	80	85
14	7.7	7.6	55	30	8

Test with Smooth Cayenne pineapple

In the duplicate set of soils, three boxes of each soil, plantings were made on July 14, 1930, two pineapple slips to each box. On August 13, the plants were well established, roots being 3 to 6 inches long. At this time *H. radicicola* was applied in the form of egg masses, approximately 50 to the cage (potentially 25,000 larvae) equally distributed between the two sides mostly at root tips but intermediately placed as well.

The initial pH of the soils was the same as in the cowpea test just described. Subsequent determinations were made by the hydrogen electrode method in A. H. P. C. chemical laboratory. They are listed, along with results in *H. radicicola* infection, in table 3.

Again, in the pineapple test, the soil hydrogen-ion concentration remained fairly consistent at the final determination, as compared with the one made shortly after planting. Those with the higher pH values dropped slightly.

The readings on nematode infection are recorded as percentage of main roots showing distinct galls. The results are not so consistent as those in cowpeas. The writers' interpretation of this lies in the inherent poorness of the pineapple

root system in indicating to any degree of accuracy minor differences in *H. radicicola* population during the first few months of growth. This conclusion is partly the result of observations conducted elsewhere than in this particular test. The difference between soils 11 and 14 in nematode infection may be due to soil differences other than soil pH, the latter being negligible. Soil 14 was a red silty clay loam, rather sticky, and probably unfavorable for nematode activity.

Irregular as are the results, they again show the possibility for nematode activity and reproduction through a rather wide range of pH values.

The correlation between pH of the soil and extent of nematode infection in pineapples was very low, as is evident from the table. As calculated, with 0.25 pH on the one hand and 10 per cent root infection on the other (the single wide variant of 8 per cent being disregarded), such correlation was -0.231 ± 0.121, definitely low, and definitely not significant.

DISCUSSION

The results in extent of nematode infection from both cowpea and pineapple tests, verify the conclusions from observation that the hydrogen-ion concentration of the soil is unimportant in determining amount of infection on the part of *H. radicicola*. Two methods of controlling soil pH were included in our tests. In the first, starting with a soil of known acidity, a range from pH 3.5 to pH 8.5 was obtained by the addition of H_2SO_4 and NaOH. In the second, field soils were selected in a range from pH 4.1 to pH 7.7. In both series, uniform heavy inoculations were made with *H. radicicola* egg masses. Since at both ends as well as intermediately on the scale infection was high, probably no adjustment of soil pH is justified from the point of view of reducing the amount of damage done to crops by this organism.

A radical difference between this conclusion and that drawn by both Peters (10) and Smith (11) for *H. schachtii* appears to merit discussion. Peters not having given a figure for coefficient of correlation with his data on the plots under study, one of the present writers considered it worth while to calculate such coefficient with 0.1 pH for the step interval on the one hand and 20 cysts on the other, using the formula:

$$r = \frac{\frac{\Sigma xy}{n} - cx\, cy}{\sigma x\, \sigma y}$$

He arrived at the figure $-.506 \pm .071$. This is a distinct negative correlation and apparently a significant one. The negative correlation is not a high one, however, and it would seem certain that some factor other than soil pH was concerned in the variations in cyst counts. The range of pH values, only 0.7 pH, would appear to be rather low for satisfactory conclusions.

Peters says (10, p. 112) "Once the eelworm had become established over the field it would presumably select the more acid environment as it appears to

have done in the Institute experimental field." By "select" in this case the writer undoubtedly meant not any activity on the part of any particular nematode, but rather the more rapid propagation of nematodes in the more favorable environment. Since, as Peters says, several generations of *H. schachtii* may develop in a single season, any slight difference in the suitability of the environment may account for considerable differences in cyst counts by the end of the season. It appears possible that a difference in host variety may have accounted for the differences that were noted. The two plots with the lowest cyst counts were of two varieties not appearing elsewhere in the table. It would appear that these particular varieties may have been somewhat resistant and may have been growing only by chance where the pH was somewhat higher than at other points. Opposed to this, of course, is Peters' statement that Morgan (who did the nematode work) could see no correlation between cyst counts and potato varieties (10, p. 108). Again, these plots may by chance have had a particularly low initial nematode population. That there must have been considerable irregularity in this respect is shown elsewhere in the data. With the variety "Ally," for example, in two separate plots which showed a difference in pH of less than 0.1, there was a difference of 76 to 43, or nearly 2 to 1, in cyst counts. Approximately the same sort of inconsistency was shown with the other variety that was duplicated in the chart.

It is to be noted that with these two varieties the individual plots with the lowest cyst counts were in one part of the field and those with the highest in another. This corresponds, of course, with the difference in pH as stated by the author. It is conceivable that it may also correspond, however, with a difference in some other factor, as for instance, moisture retention in the soil. Indeed, in the paper by Smith (11) it would appear from his figure 1, that in one of three series, an apparent negative correlation exists between moisture and cyst counts. In the other two series in this figure there was virtually no variation in the moisture content. The variability in cyst count shown may have been the normal variability within a single moisture content array. It is unfortunate that no other figures exist in the literature with a wide range of moistures in the same type of soil, by which one might judge as to the possible influence of this factor on cyst count. In Smith's paper again, only a narrow range of pH values (1.22 pH) is shown. His calculated correlation between pH within this range, and cyst count is $-.504$ with a P. E. (calculated by the present writers) of 0.069. The fact that this figure agrees very closely with that calculated on the data given by Peters, makes both appear more significant. The inconsistencies in the matter of correlation reported from other fields by both Peters and Smith, however, would seem to add weight to the possibility that soil moisture, or at least some factor other than soil pH, might have even more weight than hydrogen-ion concentration in determining the building up of populations of *H. schachtii*.

In considering further the apparent difference between *H. radicicola* and *H. schachtii* in the effect of the differences of soil pH it is to be remembered, of

course, that the latter organism lives the greater part of its life superficially on the root with its body in the soil. It is thus more directly subjected to the soil environment than is *H. radicicola* and therefore may be more greatly influenced by the hydrogen-ion concentration of the soil. The writers feel, however, that considerably more work is demanded before the final story is told for *H. schachtii*.

In verification of our conclusions from the experiments reported herein, are field observations on the occurrence of heavy *H. radicicola* infestations in both acid and alkaline soils. Such infestations are decidedly spotted at times. One spot about 10 by 20 feet in an acid soil district (pH around 4.0) showed very high infestation in its middle portion with evidences of spread with the slope of the land. Surrounding areas were free. Samples taken in this district showed, of course, extreme variation in nematode infestation with approximately the same pH throughout. On the other extreme, heavy infestations were likewise found in soils of pH around 7.5, decidedly on the alkaline side of neutrality.

SUMMARY

Tests were conducted in Hawaii with a range of hydrogen-ion concentrations between pH 4.0 and pH 8.5 to determine whether this factor of the soil environment could influence amount of damage done by the root knot nematode *Heterodera radicicola* (Greeff) Müller. These tests were conducted in two ways, (*a*) with soils adjusted to different pH values by means of additions of H_2SO_4 and NaOH, and (*b*) the collection of pineapple and sugar cane field soils of previously determined pH values, through a wide range. In the first case pineapple was used for determinations of amount of root knot development; in the second, both pineapple and cowpea were used. In no case was any great difference in amount of infection manifest. There is possibly a slight but unimportant reduction at pH values of 7.6 to 8.0 as compared with lower points.

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THE DURATION OF LIFE OF THE ROOT KNOT NEMATODE, *HETERODERA RADICICOLA*, IN SOILS SUBJECTED TO DRYING[1]

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Parallel with the laboratory studies conducted at this station on the relation of various factors of the environment of *Heterodera radicicola* eggs and larvae reported in other papers (5, 8), tests were conducted on this organism as it occurs in a soil environment. These studies had the objective in view of determining the duration of life of *H. radicicola* in soils subjected to various soil moisture conditions. The results have given a more complete understanding of what actually takes place in the field.

Very little specific information was found in the literature on this subject. The writers were encouraged in their work, however, by the results obtained in the laboratory phases of the study referred to. Certain statements in the literature were likewise encouraging as to the possibility of actually improving soil fertility by sun drying. Steenkamp (9) in particular has made some rather significant statements in this connection. He says, "The beneficial effect on fertility of drying and burning soil has long been known." Again, "The increased productivity caused by drying alluvial soil in direct sunlight has been fully recognized in India." Still further, "It is the purpose of this paper to throw more light on the problem of the increased fertility after drying." Opposed to this viewpoint, however, is the prevailing opinion as expressed by Watson (12) that long exposure of soil to sun drying "greatly impoverishes" it by destroying the humus as well as the bacteria and other organisms. It is certain, of course, that during the period of such exposure increase of organic matter by the growing of green manuring crops, which is often highly desirable, is prevented. Regardless of the merits of the fertility phases of the case, however, it is of interest to know, where root knot nematode infestation is a factor in plant growth, what the effect of exposure of infested soil to drying may be on this organism.

EXPERIMENTATION

Since each experiment described herein was slightly different from the one preceding, the various experiments are taken up separately and the specific

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methods followed are described for each. In all cases determinations on extent of nematode survival after the various treatments were made by the indicator plant method described elsewhere (4).

Experiment 1.—Effect of drying on survival of H. radicicola *in tubs of heavily infested soil*

In this preliminary test, soil from an infested field was further inoculated with nematodes contained in broken roots of infected pineapple plants. The soil was thoroughly mixed and placed in wooden tubs of 1,220 cubic inches capacity and 11-inch depth. These were then subjected to the following conditions:

Lot A. Kept continuously moist by daily addition of water.
Lot B. Allowed to dry without stirring. No moisture was added during the entire course of the experiment until time to make determination on extent of nematode survival.
Lot C. Allowed to become dry with the supplementary aid of stirring of the upper 4 or 5 inches of soil once a week.
Lot D. Hastened in its drying still further by stirring once a week to the entire depth of the soil.
Lot E. Still further hastened in its drying by completely reversing the soil by pouring from one tub to another once a week.

There were six tubs in each lot.

The tubs were set up on benches in an open-sided greenhouse which was protected from rain but permitted the free passage of air. Since the house was covered with ordinary greenhouse glass, there were no direct ultra-violet rays acting upon the surface of the soil. The test began on April 17, 1928, and continued through the summer months. The temperature at no time was high enough noticeably to injure plants growing in the greenhouse. Such mortality of nematodes as occurred was due, in all probability, to the direct effect of drying and to starvation.

At the beginning of the test, check tubs were planted to cowpeas as an indicator of primary degree of infestation of the soil. All plants showed extremely high infection—beyond the practicability of a count.

One month after the start of the series of special treatments, one tub from each of the five lots was irrigated to approximate field capacity and cowpeas were planted as indicators to measure the degree of soil infestation. Thereafter, at 4-week intervals the special treatments were discontinued on one tub from each lot, moisture was added, and cowpeas were planted. The plants were kept under good growing conditions. They were removed with roots intact after 4 weeks' growth, this being sufficient time for thorough primary infection without chance of secondary galls appearing as the result of reinfection from the progeny of the first. Readings on the degree of remaining infestation were taken in terms of approximate numbers of galls per tub. Instead of an exact count of galls, relative degrees of infestation are here recorded on the scale of

0 to 10, 0 meaning, of course, no infection; trace means 1 to 10 galls per plant; 1 means 11 to 30 galls; 2, 31 to 50 galls; 3, 51 to 100 galls; 4, 101 to 200 galls; 5, 201 to 300 galls; 6, 301 to 400 galls; and therafter jumps of 200 for each index number, up to 10 meaning 1,000 or more galls per plant. These figures are estimates only; they are not susceptible to satisfactory statistical analysis, yet they are definitely significant as to important differences in soil infestation. The number 7, for example, would mean marked infestation as compared with only light infestation where the index is 1 or 2.

Table 1 gives the results in the successive readings. It shows gradual decrease of effective nematode populations of the soil with the passage of time in all five lots. The decreases were considerably faster in those soils that were most completely dried. At the time of the fourth reading on soil treated for 16 weeks, there was 100 per cent killing in the two soils that were driest, but killing was not complete in any of the others.

TABLE 1

Observations on root knot indicator crops from experiment 1

Readings are on the scale of 1 to 10 (very slight to extreme infestation)

SERIES	TREATMENT	PERIOD OF TREATMENT				
		4 weeks	8 weeks	12 weeks	16 weeks	20 weeks
		Cowpeas				Pineapple
A	Continuous moisture	10	7	2	2	trace
B	Dry—no stirring	10	9	7	6	3
C	Dry—stirred 5 inches	10	9	1	1	0
D	Dry—stirred to bottom	10	8	1	0	0
E	Dry—soil turned over	10	2	trace	0	0

The soil that was permitted to become dry without watering and without stirring interestingly enough retained a higher nematode population at the end of the sixteenth week than did the soil which was kept continuously moist during the same period. This appeared at first anomalous in view of the fact that laboratory tests reported elsewhere (5) had shown relatively quick killing of *Heterodera* eggs and larvae at almost any humidity below saturation. At 90 per cent humidity, for example, killing of eggs in egg masses was complete in only 9 hours. Where the inoculum was in the form of infested roots, however, survival was much longer. Killing then was complete in 8 days at 80 per cent humidity. At 90 per cent humidity, however, there was still 70 per cent survival after 20 days. In the present test inoculum was in the form of infested pineapple roots. It would seem that the heavy survival indicated, after a period of 16 weeks of exposure, is to be accounted for on the basis of failure of the infested material to become completely dry. This is directly in line with the observational evidence of Rotmistrov quoted by Veihmeyer (10) and the latter's experimental evidence to the effect that in the absence of roots of growing plants, soil below the immediate surface layer will not lose its moisture

except at the extremely slow rate induced by thermal effects. Conrad and Veihmeyer (2) still further show that the rate of drying of soil is directly proportional to the abundance of living roots present in the soil. In this experiment no plants were present. It is therefore to be expected that throughout the soil, except in the surface layer, sufficient moisture was retained in the soil particles to maintain a relative humidity of 100 per cent in the soil interspaces. Under such conditions the nematode larvae lack water in which to swim and are therefore inactive; but as shown by the laboratory tests (5) long continued survival of *Heterodera* larvae and eggs will occur in an environment of 100 per cent relative humidity, in the absence of free water.

While no actual measurements were made of the humidity of the soil in this particular test, observations by means of a Fuess soil hygrometer, made later in tubs of soil and in field soils that were continuously cultivated during a dry summer, showed that this explanation is justified. Even though the soil appears superficially to be quite dry, readings were invariably 100 per cent or very nearly so for soil air humidity at any depth below the upper 2 or 3 inches of actual dust. The nematodes in such soil in the absence of free water, remained inactive but did not become dried to the killing point.

In the continuously moist soil the amount of water added daily was, unfortunately, not measured. It is impossible, therefore, to know the exact moisture content of the soil in relation to its field capacity. It is certain, however, that an excess of water was added above its moisture equivalent content, for at the close of the experiment the soil was actually soggy in the bottoms of the tubs. A film of moisture was therefore present in which the nematode larvae could maintain continuous activity after having once hatched. This continuous activity brought about gradual depletion of stored energy in the form of layers of fat in the cells of the intestinal wall which we have demonstrated for *H. radicicola*, as Goodey (7) has done for many other species of nematodes. In the absence of food they gradually starved. This conclusion is more or less theoretical but is logical in view of observed facts. No effort was made to control the possible occurrence of other organisms that might possibly have been a factor in nematode reduction in the moist soil.

At the time of this fourth reading, after 16 weeks' continuous soil treatment, lots D and E, as stated, showed no infection in the indicator crops. The 16 weeks of severe drying had apparently destroyed all infective nematodes. The other tubs in the series all showed some degree of infestation of the soil varying from 10 or 20 galls to the tub in lot C, up to 300 to 400 galls to the tub in lot B. At the time of this reading the remaining two tubs in each lot had had 20 weeks of continuous treatment. At this time these tubs, together with those upon which readings had already been taken, were watered heavily and allowed to stand for a week. They were then planted to pineapples and maintained under good growing conditions for several months. The pineapple plants were then removed from each lot. Observations were made on the pineapple roots and recorded as follows: lots C, D and E showed no infesta-

tion whatever, verifying the previous observation on the cowpea indicator that the nematodes had been completely eradicated by the drying treatment; lots A and B showed infestation in approximately the same degree as shown on the cowpea plants, a trace only in the continuously moist tubs and somewhat heavier infestation in the continuously dry but not stirred series. The pineapple root readings are significant merely in that they verify the earlier indicator crop readings and therefore justify the conclusion as to survival of the nematodes under the different conditions of the experiment.

Experiment 2.—A test of the survival of H. radicicola *eggs and larvae in soils*

The plan of this experiment called for conducting exactly parallel tests with *H. radicicola* larvae and egg masses, under a series of different moisture conditions. The soil used was pineapple field soil supplemented by the addition of 10 per cent organic matter in the form of peat moss. It was thoroughly mixed, steam sterilized, and then placed into a series of 98 four-gallon stone jars, each jar receiving exactly 7 kgm. of field soil of uniform moisture content, which was determined at the time of filling as 20 per cent of the oven-dry weight. The moisture equivalent of the soil, which was taken as the standard for moisture capacity according to the method of Briggs and McLane (1) and of Veihmeyer, et al. (11), was found to be 33 per cent. The jars were divided into two equal lots of 49 jars each. In lot A each jar was inoculated with *H. radicicola* larvae by pouring into it a suspension of about 10 cc. containing approximately 20,000 larvae obtained as described in another paper (3). This was stirred loosely into the soil in order to get approximately even distribution. Lot B was inoculated by inserting 40 egg masses, which quantity is sufficient to make approximately the same degree of initial infestation as that used in the first lot. The egg masses likewise were mixed throughout with the contents of each jar. Each of lots A and B was divided further into seven sub-lots, seven jars to each. These received the following treatments:

Sublot 1, undisturbed, surface dried, no stirring, no watering.
Sublot 2, dried by thorough stirring once a week, no watering.
Sublot 3, fluctuating between moisture equivalent and the minimum moisture attained by complete stirring once a week for a month.
Sublot 4, moisture equivalent maintained by daily weighing and water replacement.
Sublot 4, moisture equivalent maintained by daily weighing and water replacement.
Sublot 5, moisture equivalent maintained by sealing top with paraffin.
Sublot 6, dried to 75 per cent of moisture equivalent; sealed with parafin.
Sublot 7, dried to 50 per cent of moisture equivalent; sealed with paraffin.
Aeration a factor in 5, 6, and 7.

The jars were arranged on tables in a closed greenhouse with relatively uniform lighting throughout.

According to plan the treatments were continued for eight consecutive weeks when one jar from each sublot was brought to moisture equivalent water content and planted to cowpeas as a nematode indicator. Thereafter at regular

4-week periods another jar was similarly planted from each sublot until the entire 7 jars were thus tested. Each planting was examined after about 30 days' growth for survival of the nematodes, as manifested by the development of root knot.

During the course of the experiment records were maintained of water losses in those series that were allowed to become dry. These losses are expressed in table 2 in terms of percentage of moisture equivalent. The figures in the last column are the "relative wetness" of Conrad and Veihmeyer (2), or the ratio of the moisture content to the moisture equivalent expressed in percentage, at the time of the last reading. These figures provide information as to the rate and extent of drying in the dried soils.

TABLE 2

Water losses from soils allowed to dry in experiment 2

SUBLOT NUMBER	LOSS AT DIFFERENT PERIODS, IN PER CENT OF MOISTURE EQUIVALENT						RELATIVE WETNESS REMAINING
	1st 4 wks.	2nd 4 wks.	3rd 4 wks.	4th 4 wks.	5th 4 wks.	Total 20 wks.	
1	45.5	5.2	4.2	1.3	0.5	56.7	43.3
2	65.0	3.9	1.56	+	+	72.0	28.0

TABLE 3

Survival period of H. radicicola larvae and eggs in experiment 2

SUBLOT NUMBER	TREATMENT	SURVIVAL PERIOD IN WEEKS	
		Lot A (larvae)	Lot B (eggs)
1	Dried, no stirring	20	12
2	Dried, stirred	16	16
3	Fluctuating	8	20
4	Moisture equivalent	20	28
5	Moisture equivalent water sealed	8	8
6	75 per cent moisture equivalent	8	8
7	50 per cent moisture equivalent	8	20

Certain unavoidable circumstances served to vitiate the results to some extent. These were primarily excessive temperatures reached in the closed greenhouse during the summer months (the temperature reached 45°C. for brief periods on some days) and the destruction of indicator plants by rats. The latter of circumstance undoubtedly killed plants that contained immature nematodes, consequently the replants could not give the same reading as the original would have done had it survived. The result is uncertainty as to the verity of negative readings. The positive readings are reliable, however, and are stated briefly below in table 3.

The survival periods indicated are those at which the last positive reading was obtained. It can be taken for granted that at the last positive reading,

the actual amount of infection, or the "index of infection" as shown in table 1, is very low, as a rule only a trace. Whenever such index was this low, invariably the next reading 4 weeks later, was zero. As stated before, these results were vitiated by unfavorable circumstances and must not be considered reliable as to negative readings. It is very possible that under better conditions longer survival might have obtained. For example in lot 1, longer survival of eggs is to be expected, since all other observations have indicated greater hardiness in eggs than in larvae. The positive readings are of interest, however. They show definite long-time survival of *H. radicicola* eggs and larvae in a soil environment, even in the case of those soils in which moisture was low. In general (see lots, 3, and 4, and 7) the jars in which the inoculation was in the form of egg masses showed longer survival of infestation than did those that were inoculated with larvae.

Those jars that were dried without stirring showed survival for 20 weeks, which is about the same as in experiment 1. The jars dried with complete stirring showed survival for 16 weeks, which is the period at which complete mortality occurred in the first experiment. The jars subjected to fluctuations of moisture content showed relatively quick killing of larvae and survival of inoculum in the form of egg masses for 20 weeks with complete killing at 24. Those maintained at moisture equivalent showed survival in the cases of initial egg inoculum for 28 weeks. This is 8 weeks longer than in the wet lot of experiment 1. It brings into question, under moisture conditions at or below the moisture equivalent, the presence or absence of a film of moisture about the soil particles in which a nematode is capable of maintaining activity. If such film does not exist, then conditions might be considered to be ideal for long survival of nematodes either in the larval or egg form. There is then no opportunity for continuous activity, though hatching of eggs may occur; with the complete absence of drying the nematodes might theoreticallly be expected to survive for a long period. In the first test unquestionably in the continuously moist soil, a surplus of water was present and opportunity existed for hatching and for continued activity.

Experiment 3.—A test of survival of H. radicicola *larvae and eggs free in the soil and enclosed within infested roots under different soil moisture conditions*

This test was conducted under conditions very similar to those described in experiment 2. The soil used was a uniform, thoroughly mixed field soil supplemented by the addition of 10 per cent organic matter, steam sterilized and placed in 4-gallon stone jars. Its moisture equivalent was 35 per cent, at which point it was adjusted at the start of the experiment. The test was conducted in an opensided greenhouse; consequently temperatures were never higher than 32°C. (86°F.) as shown by a continuous thermographic record. The higher points mentioned were reached for only an hour or two each on two consecutive weeks; consequently temperature cannot be considered a factor in the killing of nematodes as it might have been in the previous experiment.

There were three lots of jars inoculated as follows: lot A, with a suspension of *H. radicicola* larvae, about 20 thousand to the jar; lot B, with about 40 egg masses each (roughly equivalent in potential numbers to the larva inoculation); lot C, with heavily infested pineapple root knot material, comparable with the others in nematode content. Treatments were planned as follows for lots A, B, and C. Each sublot consisted of 10 jars.

Sublot 1, drying facilitated by stirring thoroughly once a week with a trowel.
Sublot 2, moisture controlled by stirring thoroughly once a week for a month to bring the moisture content down as low as possible, then restoring to the moisture equivalent, and repeating.
Sublot 3, soil weighed daily and lost water replaced, keeping constantly at or near the moisture equivalent.
Sublot 4, moisture equivalent maintained by sealing the top with a paraffin-wax mixture poured over paper cut to fit, to a depth of about one-quarter inch. Aeration a factor.

The experiment was started on September 15, 1930. The schedule of outlined treatments was followed closely. Occasionally difficulty was experienced

TABLE 4

Survival of H. radicicola larvae, eggs in egg masses, and nematodes enclosed within roots, in soils subjected to different moisture conditions

SUBLOT NUMBER	TREATMENT	H. RADICICOLA SURVIVAL—WEEKS		
		Lot A (larvae)	Lot B (eggs)	Lot C (roots)
1	Dried, by stirring	16	20	20
2	Fluctuating	12	16	40+
3	Moisture equivalent	40+	40+	40+
4	Moisture equivalent sealed	14	14	20+

in obtaining satisfactory growth of the cowpea indicator because of heavy attacks by leafhoppers. In general, however, satisfactory indicator crop readings on infection were obtained. Unfortunately the series of jars was not extensive enough to obtain a final negative reading on all treatments. It was not learned, therefore, at what time final killing might be expected under the conditions that were more favorable for nematode life. Under the less favorable conditions complete mortality occurred before the end of the experiment.

The results of this experiment are given in table 4 as the period of time elapsed up to the final readings which showed survival, all subsequent readings being negative. Where survival was still evident at the time of the readings on the final jars of the series, it is indicated by the symbol "+" meaning "more than."

Records which were maintained of water losses in sublot 1, dried, showed, at the time of the last positive readings, relative wetness as follows: lot A, larvae, 20.9 per cent; lot B, eggs, 14.8 per cent; lot C, roots, about the same.

It has seemed from this table that again complete air drying brought about

complete killing of all the nematodes in 20 to 24 weeks. This includes those in the relatively protected condition as found within woody infested roots. The fluctuating condition of alternate drying and wetting has apparently reduced eggs and larvae in this case even quicker than the drying alone. This condition, however, permitted survival of nematodes within the roots for 40 or more weeks. The lots maintained at the moisture equivalent, unsealed, permitted of survival for 40 or more weeks throughout. The jars with the same high moisture content sealed with the paraffin-wax mixture showed much quicker killing of the contained nematodes. Some condition, at present not thoroughly understood, is probably a factor here. Possibly decomposition of organic matter permitted the accumulation of toxic gases within the jars and this condition brought about a quicker killing. In general again it is to be seen that, as might have been expected, nematodes survived for a longer period when protected by the woody roots which contained them.

Experiment 4.—The duration of life of nematodes in pineapple roots

As a final experiment in this series, an effort was made to determine the period the root knot nematode would survive in pineapple roots exposed under various conditions. Heavily infected pineapple roots contain an abundant population of this organism. This is shown to good advantage by Godfrey and Oliveira (6) in their several illustrations. When such roots became buried in the soil they make a prolific source of infection for new plantings. The release of the nematodes into the soil may take place almost immediately in the case of the more tender root tip tissues, in which the larvae, hatching out from egg masses, may travel readily to reach the soil. Those galls that have become woody, however, which include most of the non-terminal galls and the very light infections not even evident as galls, serve as a medium in which the nematodes may survive for a long period. With such, actual root decay or partial decay must take place before their release into the soil can come about. The nematodes within such roots are more or less dormant populations, in egg or larval form. Such nematodes are likely to play an important part in the survival of infestation for a new planting. Doubtless, in the field, there are enormous numbers free in the soil, but all tests to date (5) have shown that those protected by the hardened root tissues have the highest degree of resistance to unfavorable conditions.

In June, 1929, a large number of heavily infected pineapple plants were selected from a field that was to be destroyed in the fall. Those selected were relatively uniform as to bulk and degree of nematode infection. In each case the top of the stump was cut off to prevent all possibility of growth, and the roots left attached to the base of the stump for convenient manipulation. The roots were thoroughly washed to free them of all surface individuals. They were then subjected to various treatments, as outlined in table 5. After the treatments, tests for survival were made by placing the root systems, still attached to the stumps, into gallon cans of moist sterilized soil in triplicate. Here they were left under moisture and temperature conditions favorable for

nematode activity for one week, to permit of escape of contained nematodes into the soil. They were then removed, washed thoroughly to free them from surface organisms, and placed in a second lot of sterile soil for a week, and so on through several changes. Meanwhile as each lot of soil was released, it was planted to cowpea as an indicator plant. One observation for nematode survival was made at the end of 30 days. The final reading, which can be considered as the completely reliable one, was made on the remaining two cans at the end of 60 days.

In table 5 the first column includes the treatment to which the roots were subjected; the second column, by plus and minus signs, the record as to survival of infestation after the treatment concerned; and the third, the number of transfers to new sterile cans before negative readings were obtained, or in other words, the number of weeks survival of nematodes actually within the roots. This latter reading can, perhaps, be looked upon as a rough measure of the magnitude of the infestation left surviving, after the drying treatment.

TABLE 5

The survival of nematodes in infested pineapple roots

INITIAL TREATMENT	SURVIVAL AFTER TREATMENT	SURVIVAL IN WEEKS WITHIN ROOTS IN MOIST SOIL, THEREAFTER
Placed immediately in moist soil	+	9
Roots dried under July sun 2 days	+	5
Roots dried under July sun 4 days	+	4
Roots dried under July sun 6 days	+	2
Roots dried under July sun 8 days	−	0

The conclusions to be drawn from this test are that (*a*) *H. radicicola* is capable of surviving within woody roots for at least 9 weeks of conditions which favor activity, before being completely released into the real soil environment. This period may, of course, vary widely from the figure given, depending on the rapidity of decay processes and other factors; (*b*) exposure of roots to sunshine for a few days prior to plowing them in may eliminate this source of infection completely, in so far as the new planting is concerned.

Summary

Following an exhaustive study of effects of various controlled environmental factors, particularly heat, moisture, and light, on the survival of *H. radicicola* larvae and eggs, reported in a previous paper, studies were made on the duration of life of the same nematode in soils subjected to drying. Three experiments on soil heavily inoculated with this organism in various conditions in containers of about 20-liter (5-gallon) capacity, gave results as follows:

When the inoculum was in the form of heavily infested woody pineapple roots, life persisted, in soil that was dried, without stirring, for something over 20 weeks; in soil air dried with frequent stirring to hasten the drying, for 16 to 20 weeks or slightly more; in soil kept continuously wet, i.e. with an excess of moisture over "moisture equivalent' requirements,

for something over 20 weeks but to a much reduced extent, as compared with surface-dried soil; in soil kept continuously at moisture equivalent, for over 40 weeks.

When inoculum was in the form of *larvae* life persisted in surface dried soil, without stirring, for 20 to 24 weeks; in air-dried, frequently stirred soil, for 16 to 20 weeks; in soil kept continuously at moisture equivalent, for over 40 weeks; in soil fluctuating between moisture equivalent and air-dry conditions, for 12 to 16 weeks; in moisture equivalent soil kept sealed, which permitted the accumulation of decomposition gases, for 14 to 16 weeks.

Inoculum in the form of *egg masses* persisted as a rule for a period somewhat longer than when in the form of larvae at the outset.

Excess moisture, which provides a medium in which larvae may be continuously active, appears to hasten the exhaustion of their vitality (survival 20–24 weeks) as compared with soil in which high air humidity is maintained without the opportunity for continuous activity (survival 40 weeks +). The range of soil moisture contents in which this latter condition exists appears to be high, all the way, in "relative wetness," from about 50 per cent to 100 per cent.

The fluctuating condition between a slight excess of moisture and the air-dry condition, materially hastens the death of the organisms in egg and larval stages but not obviously so during the period of these experiments where they are protected by being embedded within woody roots.

Sealing the jars with a relatively high moisture content, which permits of continuous decomposition of contained organic matter, likewise hastens the death of the contained nematodes.

The root knot nematode may survive within woody roots for 9 weeks or longer, in a moist soil environment, and thus serve as a source of infection in subsequent plantings; such source of infection may be eliminated by exposure of such roots to the sun for a few days before they are plowed into the ground.

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ASSIMILATION OF PHOSPHORUS AND POTASSIUM BY BARLEY PLANTS GROWN ACCORDING TO NEUBAUER PROCEDURE AND IN UNDILUTED SOIL

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Among the numerous procedures used in attempting to ascertain the requirements of soils for plant nutrients, is that proposed by Neubauer (5, 6, 7). The essential feature of this method is the growing of a large number of rye plants in a small amount of soil mixed with sand. The quantities of phosphorus and potassium obtained from the soil indicate the available supply. This method has been used extensively in Germany where it is considered useful for ascertaining soil deficiencies. Roemer (8) applied the method to the continuously cropped soils from plots at Rothamsted and concluded that it was well adapted for determining the available plant food supply of the soil as influenced by fertilizer treatment and cropping.

In addition to the nutrient supply there are many environmental factors, including variations in temperature and moisture, that can influence the intake of nutrients by plants. Other factors that may affect the indications obtained by the plant's analysis of the soil, are the amount of soil and the influence of mixing sand with soil upon the feeding capacity of the root system of plants grown in pot tests. With conditions for root penetration and development improved there may be larger amounts of elements taken up than without sand addition.

Gericke (4) in a discussion of methods used for determining the soil supply of nutrients available for plants, directs attention to the influence of sand addition to soil in the seedling plant method of Neubauer. He states that the addition of a large amount of sand to a small amount of soil may modify the mechanical composition of the soil to the extent that its inherent individuality with respect to physical characteristics will be partially eliminated, and soils of different types therefore reduced to a common basis. This influence of sand is less noticeable in sandy and loam soils since there is sufficient opportunity for root penetration in these soils. The effect of sand addition in the case of soil of high clay content may be considerable. Under certain conditions without sand addition, the intake of root-soluble nutrients will be less than when soil is changed from its natural field condition by the addition of sand.

EXPERIMENTAL

One of the advantages claimed for the Neubauer method is that the extreme condition of competition with a large number of plants grown in a small amount of soil obscures the effect of other factors than nutrient supply to a considerable extent. The effect of a small amount of soil diluted with sand as compared with a larger amount of undiluted soil on the intake of phosphorus and potassium by plants is shown by results obtained with the plant analysis method in determining available nutrients in soil from several plots of the 5-year rotation fertility experiment at the Ohio Agricultural Experiment Station.

Soils and treatment

The soils were from plots of the 5-year rotation fertility experiments that have had additions of phosphorus supplied by superphosphate, bone meal, and basic slag supplemented with potassium and nitrogen on limed and unlimed soil. These phosphorus carriers have been applied to certain plots of this fertility experiment for 37 years. Crop yields on the limed portions of the plots in former years have exceeded those on unlimed soil. During recent years, however, the yields of oats and wheat on the limed portions of the plot treated with bone meal have tended to fall below the yields on the unlimed soil. Tests with barley plants grown in the two amounts of soils were employed for the purpose of determining whether a deficiency of available phosphorus or potassium was a factor producing this peculiar effect on crop yields following the long continued addition of bone meal as compared with other phosphorus carriers on limed soil.

The field applications of fertilizers that have been made on the plots described are stated in the tables giving the data pertaining to phosphorus and potassium obtained by plants from the differently treated soils. During the 27-year period preceding 1921 the fertilizer treatment for each 5-year period supplied phosphorus equivalent to the amount furnished by 16 per cent superphosphate at the rate of 320 pounds an acre. Since 1921 the phosphorus carriers have furnished phosphorus equivalent to 480 pounds of superphosphate. Muriate of potash has been applied at the rate of 260 pounds and nitrate of soda 320 pounds an acre each 5 years during the entire period.

The additions to soils in pots previous to the planting of barley were at the following rates per 2,000,000 pounds of soil considered as the weight per acre; superphosphate 20 per cent P_2O_5, 500 pounds; muriate of potash, 400 pounds; nitrate of soda, 125 pounds; calcium carbonate, 8,000 pounds. These additions to soil in pots were for the purpose of determining what effect modifying the soil's supply of constituents furnished by these treatments might have on the growth of plants as well as on their composition.

Methods

In applying the plant analyses method for determining the assimilable phosphorus and potassium in soil from these differently treated fertility plots,

100 barley plants were grown in 100 gm. of soil with addition of sand as prescribed by Neubauer, and in 9 pounds of undiluted soil. These were triplicate pots of each soil and treatment, and the growing period of plants in both amounts of soil was 18 days. The roots were discarded and portions of the plants above ground were used for determining the intake of phosphorus and potassium. The plants of both series were grown at the same time in a glass house with identical conditions of temperature and light, and the soils maintained at the same moisture content of 20 per cent.

PHOSPHORUS CONTENT OF PLANTS

A comparison of the phosphorus concentration or percentage in plants shows that this was higher in the barley from 100 gm. of soil as used in the Neubauer procedure. In fact the percentage of phosphorus in plants from the smaller amount of soil has rather uniformly exceeded that in plants from 9 pounds of undiluted soil by a wide margin. The percentages of phosphorus in barley plants grown under the different conditions of treatment are stated in table 1.

The larger weight of plant material generally produced in 9 pounds of soil was no doubt a factor partially accountable for the decreased phosphorus content of plants from the larger amount of soil as compared with that of the plants grown according to the Neubauer procedure. It will be noted, however, from the potassium data for plants in table 3 that the relation between weights of plants produced and their potassium content was directly opposite to that for phosphorus.

Effect of treatment on phosphorus content of plants

Considered in detail with respect to the field treatment of the soil with fertilizers and lime, and additions to pots, the variations in phosphorus content of plants from the two amounts of soil are as follows: With no additions of superphosphate or calcium carbonate to soil in pots, the previous field applications of lime materials has caused some variations in the phosphorus content or percentages in plants grown in both quantities of soil. The averages for the phosphorus content of plants grown in unlimed and limed soil, without addition of superphosphate to the pots, shows that there was a general tendency for the percentage in plants from the limed soil to be less than that of plants from unlimed soil in the Neubauer series. In the case of barley grown in 9 pounds of soil the plants from limed soil had a higher phosphorus content. With available phosphorus supplied to plants by additions of superphosphate when barley was planted there was generally an increased content of phosphorus in plants grown in both amounts of soil. This increase, however, was more pronounced in plants from the larger quantity of soil.

In the case of plants grown according to the Neubauer procedure the available phosphorus supplied by superphosphate was reflected to a greater extent by an increased percentage of phosphorus in plants grown in the limed soil. No evidence of an increased supply of phosphorus resulting from previous field applications of phosphates was furnished by the phosphorus content of plants.

TABLE 1

Phosphorus assimilation by barley plants grown in 100 gm. of soil according to the Neubauer procedure and in 9 pounds of soil

FIELD TREATMENT 5-YEAR ROTATION FERTILITY EXPERIMENT PLOTS	Additions to soil in pots*	NEUBAUER 100 GM. SOIL					9 POUNDS UNDILUTED SOIL				
		Plant weight	Phosphorus content of plants	Phosphorus balance			Plant weight	Phosphorus content of plants	Phosphorus balance		
				Phosphorus in soil†		Phosphorus removal by plants			Phosphorus in soil†		Phosphorus removal by plants
				Total	0.1 *N* H_2SO_4-soluble				Total	0.1 *N* H_2SO_4-soluble	
		gm.	*per cent*	*mgm.*	*mgm.*	*mgm.*	*gm.*	*per cent*	*mgm.*	*mgm.*	*mgm.*
Unlimed soil											
None	None	2.9	0.56	37	2	17	4.8	0.20	1,508	94	10
	$CaCO_3$	3.1	0.42	37	2	13	4.7	0.22	1,508	94	11
	P	2.9	0.61	40	5	18	4.0	0.36	1,599	183	14
	P, N	3.5	0.51	40	5	18	7.6	0.42	1,599	183	32
Superphosphate, muriate of potash, nitrate of soda	None	3.2	0.54	47	3	18	7.8	0.19	1,898	126	15
	$CaCO_3$	3.3	0.57	47	3	19	7.8	0.24	1,898	126	19
	P	3.2	0.47	50	6	15	8.2	0.37	1,989	215	30
Bone meal, muriate of potash, nitrate of soda	None	2.9	0.53	47	4	15	6.1	0.20	1,898	147	12
	$CaCO_3$	2.9	0.49	47	4	14	6.5	0.18	1,898	147	12
	P	2.8	0.64	50	7	18	7.0	0.35	1,989	236	24
	K	3.1	0.46	47	4	14	6.8	0.21	1,898	147	14
	N	2.9	0.46	47	4	13	6.2	0.19	1,898	147	12
Basic slag, muriate of potash, nitrate of soda	None	2.9	0.55	41	4	16	7.1	0.20	1,667	159	14
	P	3.2	0.54	44	7	17	8.4	0.44	1,758	248	37
Limed soil											
None	None	3.2	0.51	38	3	16	4.3	0.24	1,545	126	10
	P	3.3	0.68	41	6	23	7.1	0.47	1,636	215	33
	P, N	3.5	0.69	41	6	24	8.0	0.45	1,636	215	36
Superphosphate, muriate of potash, nitrate of soda	None	3.5	0.52	43	5	18	7.0	0.23	1,744	208	16
	P	3.4	0.73	46	8	25	8.4	0.38	1,835	297	32
Bone meal, muriate of potash, nitrate of soda	None	3.2	0.38	42	7	12	6.8	0.26	1,717	269	18
	P	3.4	0.56	45	10	19	7.5	0.46	1,808	358	34
	K	3.6	0.45	42	7	16	9.0	0.27	1,717	269	25
Basic slag, muriate of potash, nitrate of soda	None	3.5	0.53	41	5	19	6.2	0.23	1,658	192	14
	P	3.3	0.56	44	8	19	8.9	0.41	1,749	281	37

* P = superphosphate; K = muriate of potash; N = nitrate of soda.

† Plus amount supplied by pot additions of superphosphate.

Application of chemical methods to the soils from these several plots has furnished indications of variations in both the total and 0.1 *N* H_2SO_4-soluble phosphorus in these soils. Table 2 shows the increases of both forms of phosphorus in soil from unlimed and limed portions of plots fertilized with superphosphate, bone meal, and basic slag as compared with unfertilized soil. The percentage of the total phosphorus soluble in the acid used for extraction is also stated. There are larger amounts of both total and soluble phosphorus in soil from the phosphated plots, and there is no wide variation in the proportion of the total amount that was soluble in dilute acid, although this is somewhat more for the limed soil. Calculated on the basis of percentage increase over

TABLE 2

Total and 0.1 NH_2SO_4-soluble phosphorus

Pounds per acre 2,000,000 pounds of soil

PLOT TREATMENT	PHOSPHORUS		PER CENT OF TOTAL PHOSPHORUS SOLUBLE	PER CENT INCREASE OVER UNFERTILIZED SOIL	
	Total	Soluble		Total phosphorus	Soluble phosphorus
	pounds	*pounds*	*per cent*	*per cent*	*per cent*
Unlimed soil					
Unfertilized	750	46	6	...	...
Superphosphate	929	62	7	24	35
Bone meal	927	72	8	24	57
Basic slag	819	78	10	9	70
Limed soil					
Unfertilized	809	63	8	....	...
Superphosphate	856	102	12	6	62
Bone meal	834	132	16	3	110
Basic slag	813	94	12	0.5	49

the unfertilized soil, the increased content of soluble phosphorus exceeds that for total phosphorus in soil from the phosphated plots.

Relation between soil phosphorus supply and removal by plants

In considering the relation of the amount of phosphorus in the soil to removal by plants, one could infer that the removal should be greater with an increased supply at the disposal of plant roots in 9 pounds of soil. The fact is, however, that this did not generally occur except in the case of plants from soil with readily available phosphorus supplied by superphosphate just before planting. A factor that may have had an appreciable influence in this connection, is the relatively greater proportion of phosphorus supplied in 100 gm. of soil by the barley seed. The barley seed contained 0.461 per cent of phosphorus and 0.547 per cent potassium. Calculated on the basis of 3.76

TABLE 3

Potassium assimilation by barley plants grown in 100 gm. of soil according to the Neubauer procedure and in 9 pounds of soil

FIELD TREATMENT 5-YEAR ROTATION FERTILITY EXPERIMENT PLOTS	Additions to soil in pots*	NEUBAUER 100 GM. SOIL				9 POUNDS UNDILUTED SOIL			
		Plant weight	Potassium content of plants	Potassium balance		Plant weight	Potassium content of plants	Potassium balance	
				Exchangeable potassium in soil†	Potassium removal by plants			Exchangeable potassium in soil†	Potassium removal by plants
		gm.	*per cent*	*mgm.*	*mgm.*	*gm.*	*per cent*	*mgm.*	*mgm.*
Unlimed soil									
None	None	2.9	1.28	3.9	38	4.8	2.72	159	131
	$CaCO_3$	3.1	1.50	3.9	46	4.7	2.20	159	103
	P	2.9	1.46	3.9	43	4.0	2.15	159	86
	P, N	3.5	1.18	3.9	41	7.6	2.78	159	211
Superphosphate, muriate of potash, nitrate of soda	None	3.2	1.99	9.8	65	7.8	4.35	400	339
	$CaCO_3$	3.3	1.78	9.8	58	7.8	3.87	400	302
	P	3.2	2.17	9.8	69	8.2	3.45	400	283
Bone meal, muriate of potash, nitrate of soda	None	2.9	2.32	7.8	66	6.1	4.75	318	290
	$CaCO_3$	2.9	2.27	7.8	66	6.5	3.97	318	258
	P	2.8	2.48	7.8	68	6.9	3.95	318	273
	K	3.1	3.88	18.0	120	6.8	5.83	763	396
	N	2.9	2.03	7.8	59	6.2	4.40	318	273
Basic slag, muriate of potash, nitrate of soda	None	2.9	1.58	9.8	45	7.1	3.26	400	231
	P	3.2	1.56	9.8	51	8.4	3.35	400	281
Limed soil									
None	None	3.2	1.13	3.5	37	4.3	1.70	143	73
	P	3.3	1.38	3.5	46	7.1	1.40	143	99
	P, N	3.5	1.16	3.5	40	8.0	1.48	143	118
Superphosphate, muriate of potash, nitrate of soda	None	3.5	1.44	5.5	50	7.0	3.21	224	225
	P	3.4	1.57	5.5	53	8.4	3.21	224	271
Bone meal, muriate of potash, nitrate of soda	None	3.2	1.46	5.1	46	6.8	2.22	208	151
	P	3.4	1.42	5.1	48	7.5	2.43	208	182
	K	3.6	3.38	15.3	123	9.0	2.52	653	227
Basic slag, muriate of potash, nitrate of soda	None	3.5	1.32	5.5	46	6.2	2.82	224	175
	P	3.3	1.34	5.5	44	8.9	2.65	224	236

* P = superphosphate; K = muriate of potash; N = nitrate of soda.

† Plus potassium supplied to pots by muriate of potash.

gm. as the weight of 100 seeds there was 17 mgm. of phosphorus that could be drawn on by plants. The intake of phosphorus from 100 seeds by barley plants grown in sand was 6 mgm. in the tops and 9 mgm. in the roots. This addition by the seed to 9 pounds of soil is probably not significant, but possibly may not be a negligible increase to the phosphorus supply in 100 gm. of soil. Dreyspring (2), in a discussion of the phosphorus content of soils of different countries, directs attention to the phosphorus supplied by the seed. He states that 100 rye grains for instance contain about 20 mgm. of phosphoric acid, whereas a soil very poor in phosphoric acid yielded only a few tenths of a milligram of phosphoric acid to the germinating plants.

The addition of superphosphate to the soil in pots supplied 3 mgm. of phosphorus to 100 gm. of soil, and 89 mgm. to 9 pounds of soil. The removal by germinating plants in the Neubauer soil medium was from 30 to 50 per cent of the total phosphorus supply of the soil, but not more than 2 per cent of the phosphorus supply was removed from 9 pounds of soil. If the phosphorus supply of the soil is considered on the basis of the amount soluble in 0.1 *N* H_2SO_4, the removal by plants in the Neubauer method was considerably in excess of the soil supply, whereas the plants grown in 9 pounds of soil removed not more than 17 per cent of the amount in the soil.

In the case of 9 pounds of soil there is a wide margin between the soil supply of total phosphorus and the amount in 100 barley seeds, but in 100 gm. of soil the seed supply of phosphorus more nearly approaches that of the soil. Dreyspring (3) found that on an average about 4 plant food units of assimilable phosphoric acid must be present in the soil in order that 1 unit may be assimilated by the plant during the first year of vegetation. In other words the plant during the first year of vegetative growth is able to assimilate only about 25 per cent of the root soluble phosphoric acid in the soil.

POTASSIUM CONTENT OF PLANTS

A reversal from the phosphorus assimilation by plants occurred in the case of potassium intake from the two quantities of soil in which 100 barley plants were grown. For in all instances the percentage of potassium in plants from the larger amount of soil exceeded to a considerable extent that in plants grown in 100 gm. of soil used in the Neubauer procedure. Table 3 shows the potassium content of plants. A more extensive root system developed by plants in the larger amount of soil may have been a factor contributing to the increased amount of potassium obtained from 9 pounds of soil. Bartholmew and Jansen (1), in an extensive study of absorption of potassium by plants, found that increased root development caused a greater feeding upon the replaceable potassium of soil.

Effect of soil treatment on potassium content of plants

There is a close correlation between the potassium content of the plants and the fertilizer treatment of the soil. The increased percentage of potassium in

plants grown according to the Neubauer procedure and in the larger amount of soil shows that there is more assimilable potassium in the soil from plots that had potassium included in the fertilizer treatment. Addition of available potassium when barley was planted produced a further increase in the potassium content of plants on these soils fertilized with potassium.

The lower percentage of potassium in plants grown on limed as compared with unlimed soil from several differently fertilized plots indicates that the reaction of the soil or its supply of calcium as modified by field applications of limestone has affected the capacity of the plants to assimilate potassium. This effect on the intake of potassium by plants grown in both quantities of soil in these experiments is in accord with the interrelation of potassium and calcium frequently found in investigations pertaining to absorption of ions by plants grown in soil and solution cultures. Tyson (9), in a study of the influence of soil conditions and fertilizer treatment upon the chemical composition of sugar beets, found that the application of lime caused a decrease in the potassium content of both leaves and roots.

Another noticeable difference in the potassium content of plants as influenced by the previous fertilizer treatment of the soil, is the decreased percentage in plants grown in soil from the limed as compared with the unlimed portion of the plot fertilized with bone meal. This condition of the potassium supply indicated by the plants' analysis of the soil may be a factor affecting the crop yields on the limed soil of this plot.

Relation between the potassium supply and removal by plants

The soil supply of replaceable or exchange potassium and the amounts removed by plants from the two amounts of soil are stated in table 3. Where the relation between the potassium supply and removal by plants is considered, the amount in soil is based on the replaceable potassium. This, of course, is not on a comparable basis with the total phosphorus supply but is more so with the soil phosphorus soluble in 0.1 *N* acid.

The soil from the plot that has not had any fertilizer treatment contained 3.9 mgm. of exchangeable potassium. Plants grown in sand obtained only 9 mgm. of potassium from 100 seeds that contained 21 mgm. Whether this was the amount that was obtained from the seed by plants when grown in soil with addition of sand and in undiluted soil is not known. Assuming that 9 mgm. was obtained from the seed, the plants grown in 100 gm. of unfertilized soil without any additions to pots obtained 25 mgm. in excess of the total exchangeable potassium and that obtained from the seed.

The 100 gm. of unlimed soil from the plot that had potassium furnished by the fertilizer treatment contained 7.8 mgm. of exchangeable potassium. The increased removal over this amount and that obtained from the seed by plants, excluding roots was 48 mgm. With 10 mgm. of available potassium supplied to 100 gm. of this soil by muriate of potash when barley was planted, the increase over the average removal by plants from the same fertilized soil with-

out further addition of potassium was 55 mgm. for the unlimed and 74 mgm. for the limed soil. A similar comparison for the removal from 9 pounds of unlimed soil shows an increase of 123 mgm., which is only 25 per cent of the 445 mgm. of available potassium added by muriate of potash.

The intake by barley plants from 100 gm. of the Wooster silt loam soil without addition of potassium when barley was planted shows that the removal was 21 mgm. more from soil previously fertilized with potassium than from unfertilized soil. Considering that 1 acre of this soil to a depth of 7 inches weighs approximately 2,000,000 pounds, an assimilation by plants of 1 mgm. of potassium from 100 gm. of soil corresponds to about 20 pounds of potassium per acre. Therefore the increased removal of 21 mgm. of root-soluble potassium by plants from 100 gm. of soil fertilized with potassium corresponds to 420 pounds of available potassium per acre.

The ratio of increased potassium in fertilized soil, as determined by chemical analysis, to the amount indicated by increased root solubility or analyses by the plant is about 1 to 3.5. There was a small increased weight of plants from potassium fertilized as compared with unfertilized soil, but there was a close relationship between the percentage or concentration of potassium in the plants and the amount removed from the soil, the magnitude of the former having affected the magnitude of the latter.

Removal by Barley Plants and Neubauer's Limiting Values for Root-Soluble Phosphorus and Potassium

According to Neubauer the following amounts of phosphorus and potassium in readily available form should be contained in 100 gm. of soil in order to produce high yields of different crops without application of fertilizers.

	Neubauer's Values	
	mgm. Phosphorus	*mgm. Potassium*
Barley and straw	3	12
Oats and straw	4	14
Wheat and straw	4	13
Rye and straw	4	14
Red clover hay	4	21
Potatoes with tops and leaves	4	30

Larger amounts of phosphorus and potassium than these limiting values were obtained by barley plants from Wooster silt loam soil. Deducting the removal of 6 mgm. of phosphorus obtained from seed by plants grown in sand, the average removal of phosphorus from 100 gm. of soil that had no addition of available phosphorus when barley was planted, is 10 mgm. The potassium removal from unfertilized soil by plants, less the amount from seed, was 27 mgm. In the case of soils that had previous fertilizer application of potassium there is a much wider margin between Neubauer's figures and the amounts of potassium obtained by barley plants. As the phosphorus assimilation by

barley plants does not indicate a deficiency of available phosphorus the results obtained by the plants analysis of the soil are not in agreement with crop response to phosphates on this soil. The results for potassium are more closely in accord with the field experiments with fertilizers.

SUMMARY

Plants grown according to the Neubauer procedure in a small quantity of soil and in a larger amount of undiluted soil furnished different indications regarding the phosphorus and potassium supply in soils of fertility experiment plots.

In this comparison of plants' intake of nutrients from two amounts of soil, 100 barley plants were grown for 18 days in 100 gm. of soil diluted with 300 gm. of pure quartz sand and in 9 pounds of undiluted soil.

The intake of phosphorus and potassium was influenced by the quantity of soil. There is an inverse relation between the percentage content of phosphorus and potassium in plants and the amount of soil. The plants grown in 100 gm. of soil contained more phosphorus whereas the potassium content was considerably greater in plants grown in the larger amount of soil.

Application of the plant analysis method for determining the available phosphorus supply in soils of fertility experiment plots did not furnish significant indications of increased amounts of phosphorus residual from superphosphate, bone meal, and basic slag. Available phosphorus supplied by superphosphate when the barley was planted was more consistently indicated by the phosphorus content of plants and removal from the larger amount of soil.

Both the Neubauer seedling procedure and the method of growing plants for the same length of time in undiluted soil as generally followed in vegetative tests showed there was a reserve supply of potassium in soil fertilized with muriate of potash.

According to the results obtained in this investigation, the plant analysis method proved to be satisfactory for furnishing information regarding the available potassium reserves from previous fertilizer treatment but failed to indicate differences in the phosphorus supply of unfertilized and phosphated soils.

Apparently barley grown in 100 gm. of soil according to the Neubauer method had the capacity to assimilate considerable potassium from other forms than that in exchangeable combination.

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INFLUENCE OF ORGANIC MATTER ON CROP YIELD AND ON CARBON-NITROGEN RATIO AND NITRATE FORMATION IN THE SOIL[1]

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In an earlier paper (1) it was shown that under some conditions organic matter, in large amounts, greatly depressed non-legume crop yields. For legumes the yields were about the same on the check cylinders as on those that received heavy applications of organic matter. The difference seems to be due to the fact that the large supply of organic matter results in the rapid increase of soil microörganisms and that these in turn compete with the plant for the nitrogen which is in the soil and in the applied organic matter. In this connection Russell (3, p. 371) says:

> The addition of plant residues to the soil is a normal occurrence and a recognised method of manuring land. The effects produced depend on the proportions of carbohydrate and protein present in the residues. If the conditions are favourable to the activity of micro-organisms the result of the addition is to cause an increase in numbers and in activity of the microorganisms: this is shown by increases in oxygen absorption and CO_2 evolution.

He explains that if the material is rich in energy supply but not in nitrogen the organisms may assimilate nitrate or ammonia already existing in the soil and thus reduce the amounts of these substances present.

It is just this condition which obtains in the cylinder soils to which the rye straw has been added. With large applications of organic matter the competition becomes so keen that the non-legume plant often suffers and the yield is reduced. On the other hand, the legume, if inoculated, has an unlimited reserve of nitrogen and therefore is not disturbed in its growth by the greatly increased microörganic population which robs the non-legume of its supply of nitrogen.

The work of the first 3 years was reported in the aforementioned paper. It seemed desirable, however, to continue the work for the purpose of noting (*a*) the effect of heavy applications of a mineral nitrogenous fertilizer on the yield, where the applications of organic matter were heavy, and (*b*) the effect of the organic matter on the carbon-nitrogen ratio, total nitrogen, and nitrate nitrogen of the soil.

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and bacteriology.

As in the previous experiment the work was conducted in cylinders with the following special treatment for each series:

Two cylinders with no organic matter
Two cylinders with rye straw cut fine, 1 ton an acre
Two cylinders with rye straw cut fine, 2 tons an acre
Two cylinders with rye straw cut fine, 4 tons an acre
Two cylinders with rye straw cut fine, 8 tons an acre

The straw was worked into the soil to the depth of 4 or 5 inches just before planting. Each cylinder received 20 gm. of superphosphate (640 pounds an acre) and 10 gm. of muriate of potash. The standard application of nitrate of soda was 10 gm. for a cylinder, but in certain cases two and even three times

TABLE 1

Yields of dry matter from soybeans, barley, and oats—1924–1931

CYLINDER NO. AND DATE / SPECIAL TREATMENT (ACRE BASIS)	SOYBEANS					BARLEY					OATS				TOTAL BARLEY AND OATS
	121–130 1924	131–140 1924	121–130 1925	131–140 1925	Total	141–150 1924	141–150 1925	141–150 1926	141–150* 1930	151–160† 1930	141–150† 1927	151–160* 1927	121–130‡ 1931	131–140† 1931	
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
No rye straw	176	279	73	124	652	137	72	77	77	67	43	98	158	38	767
1 ton rye straw	201	289	107	125	722	132	73	67	40	32	41	98	177	29	689
2 tons rye straw	203	288	120	143	754	118	92	81	64	31	40	79	157	35	697
4 tons rye straw	167	190	79	125	561	75	84	61	64	36	29	54	164	37	604
8 tons rye straw	186	243	138	147	714	46	91	58	45	35	40	51	176	48	590

* One extra 10-gm. portion $NaNO_3$.

† No nitrogen.

‡ Two extra 10-gm. portions $NaNO_3$.

this amount was applied. Certain series also received no nitrogen. These variations are indicated in the tables.

In a number of cases the heavier applications of straw did have a depressing effect on yield, though this did not prove as serious after the experiment had been running for some time as it was the first year.

The yields for three of the crops, soybeans, barley, and oats, for the years 1924 to 1931 are shown in table 1.

In the case of the soybeans grown in 1924 and 1925, it will be noted that organic matter applied at the rate of 8 tons an acre did not have a depressing effect on the yield. It is true that the total yield for the 2 years, with 4 tons of straw is lowest, but this must be attributed to other causes than the depressing effect of the straw since the yields without straw and with 1, 2, and 8 tons to the acre are larger than with the 4 tons.

With the non-legumes—barley and oats—the yields in some cases show a decrease with increase of organic matter, whereas in other cases they run about

constant or even show an increase. For example, the barley grown in 1924 shows a very decided decrease as the amount of organic matter was increased. The yields for the same crop in 1925 tend to show an increase with increased amount of straw rather than a decrease, but this is undoubtedly due to the fact that no straw was applied in 1925. With certain exceptions there is a gradual decrease in the yield for the years 1926 and 1930.

Where no nitrogen was applied for the oats the crop was so poor that the figures have little meaning. When two extra 10-gm. portions of nitrate of soda were applied (cylinders 121–130, 1931), there is no indication of a depressing effect due to the organic matter. With one extra 10-gm. portion of nitrate of soda in 1927, the heavier applications of rye straw had a distinct depressing effect on the yield.

TABLE 2

Yield of dry corn forage—1924–1931

CYLINDER NO. AND DATE / SPECIAL TREATMENT (ACRE BASIS)	151–160 1924	151–160 1925	121–130* 1926	131–140* 1926	151–160† 1926	151–160 1928	141–150‡ 1929	151–160‖ 1929	121–130‖ 1930	131–140‡ 1930	141–150§ 1931	151–160‡ 1931	TOTAL
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
No rye straw	288	288	719	702	342	204	106	180	479	215	752	132	4,407
1 ton rye straw	306	323	734	731	354	205	85	226	597	163	754†	147‡	4,625
2 tons rye straw	240	303	747	778	309	164	76	159	573	148	713	108	4,318
4 tons rye straw	192	310	609	675	294	131	83	149	461	116	591	93	3,704
8 tons rye straw	154	373	642	672	310	103	72	110	629	194	527	114	3,900

* Cylinders 121–140 received nitrogen equivalent to 40 gm. $NaNO_3$ per cyclinder, in two applications.

† 10 gm. nitrate of soda extra.

‡ No nitrogen.

‖ 2 extra 10-gm. portions $NaNO_3$.

§ 3 extra 10-gm. portions $NaNO_3$.

Table 2 shows the yields of dry corn forage grown on the different series of cylinders for the years 1924 to 1931. In some cases no nitrogen was applied; in other cases the normal application was given; and in still other cases extra portions were applied. Where no nitrogen was applied the yield generally decreases as the amount of organic matter applied increases. This also holds true where the single portion of nitrate was applied in 1924 and 1928. It does not hold true for 1925, but no straw was applied for that year, and no doubt the effect of the straw applied in 1924 had largely disappeared. Where the larger amounts of nitrate were applied, the yields did not show the same tendency to decrease with increase of straw as where no nitrogen was applied. Plate 1 shows the effect of the heavy applications of nitrate on the corn.

These figures strengthen the claim that the depressing effect of the organic matter is due to the competition between the growing plant and the micro-

TABLE 3

Percentage of nitrogen—soybeans, barley, and oats—1924–1931

SPECIAL TREATMENT (ACRE BASIS) / CYLINDER NO. AND DATE	SOYBEANS				BARLEY						OATS						AVERAGE
					Grain	Straw							Grain	Straw	Grain	Straw	
	121–130 1924	131–140 1924	121–130 1925	131–140 1925	141–150 1924	141–150 1924	141–150 1925	141–150 1926	141–150* 1930	151–160† 1930	141–150† 1927	151–160* 1927	121–130‡ 1931	121–130‡ 1931	131–140† 1931	131–140† 1931	
No rye straw	2.65	2.28	2.00	2.25	2.04	0.62	1.29	1.64	1.76	1.72	1.03	1.55	2.71	1.30	1.96	1.04	1.74
1 ton rye straw	2.91	2.37	2.05	2.32	1.96	0.52	1.31	1.57	2.12	1.44	0.95	1.45	2.58	1.27	1.91	1.33	1.75
2 tons rye straw	2.74	2.40	2.14	2.28	1.98	0.50	1.29	1.34	1.98	1.35	1.08	1.48	2.62	1.27	2.09	1.20	1.73
4 tons rye straw	2.22	2.32	2.28	2.33	1.82	0.56	1.47	1.32	1.84	1.39	1.14	1.50	2.68	1.19	2.11	1.32	1.72
8 tons rye straw	2.58	2.58	2.11	2.41	1.78	0.68	1.53	1.26	1.70	1.54	1.26	1.54	2.57	1.13	2.45	1.16	1.77

* One extra 10-gm. portion $NaNO_3$.

† No nitrogen.

‡ Two extra 10-gm. portions $NaNO_3$.

TABLE 4

Percentage of nitrogen—corn forage—1924–1931

SPECIAL TREATMENT (ACRE BASIS) / CYLINDER NO. AND DATE	151–160 1924	151–160 1925	121–130* 1926	131–140* 1926	151–160† 1926	151–160 1928	141–150‡ 1929	151–160‖ 1929	121–130‖ 1930	131–140‡ 1930	141–150§ 1931	151–160‡ 1931	AVERAGE
No rye straw	0.382	0.353	0.486	0.565	0.592	0.570	0.663	1.116	0.770	0.496	0.447	0.501	0.578
1 ton rye straw	0.387	0.394	0.532	0.541	0.567	0.559	0.702	0.984	0.710	0.520	0.443	0.551	0.574
2 tons rye straw	0.427	0.356	0.532	0.532	0.547	0.678	0.710	0.996	0.596	0.624	0.506	0.551	0.588
4 tons rye straw	0.427	0.381	0.551	0.609	0.564	0.768	0.698	0.984	0.929	0.596	0.517	0.686	0.643
8 tons rye straw	0.527	0.373	0.552	0.651	0.619	0.757	0.704	0.859	0.541	0.801	0.578	0.678	0.637

* Cylinders 121–140 received nitrogen equivalent to 40 gm. $NaNO_3$ per cylinder in two applications.

† 10 gm. nitrate of soda extra.

‡ No nitrogen.

‖ Two extra 10-gm. portions $NaNO_3$

§ Three extra 10-gm. portions $NaNO_3$.

organic population of the soil for the available supply of nitrogen. With a limited amount of nitrogen the plant suffers. With an abundance of nitrate nitrogen the plant gets its needed supply, and the difference in yield between those that receive no straw, or small amounts, and those that receive large amounts, is not great. Table 3 shows the percentage of nitrogen in the dry matter of soybeans, barley, and oats, and table 4 shows the percentage of nitrogen in the corn forage. From the averages in table 3 it is evident that the rye straw has had little or no influence on the percentage of nitrogen in the crop. In some cases the highest percentages are found in crops from cylinders with no rye straw and in other cases in crops from cylinders that received the heavy applications of rye straw.

In the case of the corn forage, table 4, there is in most of the tests, a slight increase in percentage of nitrogen as the amount of rye straw was increased. The increase is slight, however, and may have little meaning.

Calculations of the total nitrogen returned through these crops for the period 1924 to 1931 show the following totals:

	SOYBEANS	BARLEY	OATS	CORN FORAGE
	gm.	*gm.*	*gm.*	*gm.*
No straw	15.30	6.34	4.83	24.22
1 ton rye straw	17.62	4.82	4.95	25.58
2 tons rye straw	18.26	5.26	4.51	23.76
4 tons rye straw	12.81	4.52	4.27	23.58
8 tons rye straw	17.48	3.92	4.55	23.00

It can scarcely be said that the heavy applications of organic matter influenced the yield of total nitrogen in the soybeans one way or the other. With the barley and corn forage the general tendency is in the direction of a slight decrease with increase of organic matter.

INFLUENCE OF RYE STRAW ON THE NITROGEN AND CARBON CONTENT OF THE SOIL

Samples of soil were collected from these cylinders in 1931 for the purpose of determining the influence of the organic matter on the nitrogen and carbon content of the soil. Table 5 shows the percentages of total nitrogen and carbon and the carbon-nitrogen ratios for the four series with the different organic matter treatments.

Total nitrogen

With slight exception there is a gradual increase in the percentage of nitrogen and carbon with increase of rye straw. An average of the nitrogen percentages for the four series shows a difference of 0.02 per cent between the cylinders without straw and those that receive 8 tons of straw to the acre. This increase seems small, but calculated on the basis of 2,000,000 pounds of soil to the

plowed acre, it would amount to a gain of 400 pounds of nitrogen to the acre during the period 1924 to 1931.

The nitrogen content of this soil, when the work was started in 1924, was 0.0985 per cent and the pH 6.5.

By way of comparison, in field experiments under a 5-year rotation of corn, oats, wheat, and 2 years of timothy, with manure at the rate of 16 tons an acre annually in addition to a complete fertilizer which carries 320 pounds of nitrate of soda an acre, it has taken about 25 years to raise the nitrogen content of the top $6\frac{2}{3}$ inches of soil from 0.11 per cent to 0.134 per cent (2).

Total carbon

The total carbon is in reality organic carbon, since carbonates are not present in this soil.

TABLE 5

Total nitrogen, carbon, and carbon-nitrogen ratio in cylinder soils—1931

SPECIAL TREATMENT (ACRE BASIS)	CYLINDERS 121–130			CYLINDERS 131–140			CYLINDERS 141–150			CYLINDERS 151–160		
	Nitrogen	Carbon	Carbon-nitrogen ratio	Nitrogen	Carbon	Carbon-nitrogen ratio	Nitrogen	Carbon	Carbon-nitrogen ratio	Nitrogen	Carbon	Carbon-nitrogen ratio
	per cent	*per cent*		*per cent*	*per cent*		*per cent*	*per cent*		*per cent*	*per cent*	
No rye straw	0.110	1.18	10.7	0.101	1.37	13.6	0.105	1.33	12.7	0.099	1.30	13.1
1 ton rye straw	0.109	1.39	12.8	0.103	1.34	13.0	0.103	1.31	12.7	0.100	1.31	13.1
2 tons rye straw	0.111	1.46	13.2	0.107	1.45	13.6	0.108	1.41	13.1	0.106	1.45	13.7
4 tons rye straw	0.114	1.61	14.1	0.110	1.53	13.9	0.111	1.52	13.7	0.109	1.45	13.3
8 tons rye straw	0.129	1.99	15.4	0.123	1.82	14.8	0.125	1.73	13.8	0.118	1.69	14.3

Table 5 shows that the carbon, like the nitrogen, increases gradually from the cylinders without straw to those that receive 8 tons an acre. The average for all the check cylinders is 1.3 per cent carbon and for those that receive 8 tons of straw 1.81 per cent, an increase of 0.5 per cent. This also seems a small increase, but it serves to indicate how difficult it is to raise the nitrogen and carbon content of soils above the amount present under apparently normal or natural conditions.

Carbon-nitrogen ratio

The figures for the carbon-nitrogen ratio are also shown in table 5. With one exception, the ratio is fairly constant for the first three treatments, that is, with no straw and with 1 and 2 tons to the acre. With one exception, a wider ratio is noted where 4 and 8 tons of the straw were used. This is in agreement with work reported by others. Russell (3, p. 313) in discussing the decomposition of soil organic matter says:

The changes affecting the carbon and those affecting the nitrogen are intimately associated. The nitrogen can appear as nitrate only if it exceeds a certain critical amount relative to the carbon—usually if the ratio C/N is 12 or less. When the proportion of carbon is greater the excess goes off as CO_2 and the nitrogen remains as complex protein: any ammonia or nitrate present is also converted into protein. When, on the other hand, the proportion of nitrogen becomes greater the excess is changed into nitrate which may be taken by plants or otherwise lost from the soil. Whatever the initial composition of the plant substances added, and whatever their form, whether straw, leaves, or animal faeces, the final humus has much the same composition and properties, and its C/N ratio in temperate regions is usually about 10–12; however this be disturbed it always comes back to its normal value.

Organic matter (organic carbon × 1.724)

Organic matter in these soils was calculated from the organic carbon using the factor 1.724. Table 6, cylinders 121–130, shows that the increase in organic matter, due to the rye straw, is greater in this series than for the other series, the difference between the check and the highest rye straw treatment being 1.39

TABLE 6

Organic matter (organic carbon x 1.724) and loss on ignition—cylinder soils, 1931

SPECIAL TREATMENT (ACRE BASIS)	CYLINDERS 121–130		CYLINDERS 131–140		CYLINDERS 141–150		CYLINDERS 151–160		AVERAGE DIFFERENCE BETWEEN ORGANIC MATTER AND VOLATILE MATTER
	Organic matter	Loss on ignition	Organic matter	Loss on ignition	Organic matter	Loss on ignition	Organic matter	Loss on ignition	
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
No rye straw.....	2.04	3.94	2.36	3.95	2.29	4.18	2.24	4.03	1.79
1 ton rye straw.....	2.40	4.07	2.30	3.94	2.26	4.18	2.25	4.02	1.75
2 tons rye straw....	2.51	4.26	2.50	4.23	2.43	4.15	2.50	4.22	1.73
4 tons rye straw....	2.78	4.59	2.64	4.33	2.62	4.34	2.58	4.29	1.73
8 tons rye straw....	3.43	5.08	3.14	4.91	2.98	4.91	2.91	4.71	1.79

per cent, whereas the corresponding difference for cylinders 131–140 is 0.78 per cent; for cylinders 141–150, 0.69 per cent; and for cylinders 151–160, 0.67 per cent. The average increase is 0.88 per cent, which, on the basis of the plowed acre, would be equivalent to nearly 18,000 pounds of organic matter.

In the work reported here this increase seems to have proved detrimental rather than beneficial. This detrimental effect is due in part to an excessive amount of the straw and in part to the fact that not sufficient time was allowed to elapse between the time of applying the straw and planting the crop.

In general practice such an increase in organic matter content would mean much in the way of increased water-holding capacity, increased food for microorganisms, and improved soil tilth.

Loss on ignition

Oven-dried samples of the soil were ignited to determine loss of volatile matter. The results are shown in table 6 along with the organic matter. With

slight exception, the loss increases as the amount of straw applied increases. The average loss for the check cylinders is 4.03 per cent and for those that receive 8 tons of straw to the acre it is 4.9 per cent, a difference of almost 1 per cent in favor of the large application of straw.

It will be noted that the average difference between the percentage of organic matter and the loss on ignition for the different treatments is about 1.75 per cent. This means that for this particular soil the percentage of organic matter could be approximately arrived at by subtracting 1.75 from the percentage of volatile matter. It does not follow, however, that this method of arriving at the organic matter could be used with soils in general.

Soil reaction

The pH of the original soil was 6.5. When the work was started in 1924 pulverized limestone was applied at the rate of 125 gm. for each cylinder (2 tons per acre). Determinations made at intervals during the first 3 years show that the pH ranged from about 6.4 to 7.0. There was no indication of a relation between the pH of the soil and the amount of organic matter applied.

TABLE 7

Soil reaction

CYLINDER NUMBER	pH	CYLINDER NUMBER	pH	CYLINDER NUMBER	pH	CYLINDER NUMBER	pH
121	6.48	131	5.86	141	6.44	151	5.95
122	6.14	132	5.75	142	6.30	152	5.93
123	6.63	133	5.79	143	6.48	153	5.86
124	6.50	134	5.69	144	6.30	154	5.74
125	6.10	135	5.74	145	6.74	155	6.00
126	5.84	136	5.77	146	6.58	156	6.15
127	6.63	137	5.85	147	6.88	157	5.95
128	6.58	138	5.84	148	6.62	158	6.10
129	6.41	139	5.97	149	6.25	159	6.07
130	6.51	140	5.95	150	6.58	160	6.16
Average	6.38	Average	5.82	Average	6.52	Average	5.99

Determinations of pH made July 7, 1932, are shown in table 7.

In this connection it will be remembered that cylinders 121 to 130 and 141 to 150 receive heavy applications of nitrate of soda as a source of nitrogen, whereas cylinders 131 to 140 and 151 to 160 do not receive nitrate of soda or other commercial form of nitrogen. It is interesting in this connection to note that those cylinders which receive the nitrate of soda show, in the majority of cases, a pH between 6.5 and 7.0, whereas those that receive no nitrate of soda, in the majority of cases, show a pH between 5.7 and 6.0. Thus those that receive the nitrate of soda show a pH approximately a half point above those that receive no nitrate of soda. From this it is evident that the nitrate of soda has had a certain corrective effect, in that the reaction has been maintained at near

the neutral point, while those that do not receive nitrate of soda are gradually becoming more acid.

Nitrates

Nitrate determinations were made on samples of the soil at intervals while the crops were growing for the period 1925 to 1930. The results are shown in table 8. The figures indicate that only in a few instances did nitrates accumulate to any extent. Determinations on duplicate cylinders are frequently not

TABLE 8

Nitrates in cylinder soils—1926–1930

(Parts per million)

Special treatment (acre basis)	Cylinder no. and date of sampling	Corn		Soybeans		Oats		Carrots	Corn	Rye	Average
		121–130*	131–140*	121–130	131–140	141–150†	151–160‡	141–150‖	151–160‖	141–150	
		8/25 1926	8/25 1926	7/12 1927	7/12 1927	7/2 1927	6/21 1927	9/6 1928	9/6 1928	5/3 1930	
No rye straw	a	1.00	1.01	1.60	6.80	0.36	0.41	6.16	9.1	2.72	3.24
	b	1.12	0.46	4.32	10.00	0.40	0.41	2.22	8.7	1.51	3.24
1 ton rye straw	a	2.08	0.56	3.00	5.00	0.50	0.81	1.60	8.4	2.39	2.70
	b	0.80	0.48	1.01	6.68	0.37	0.76	2.10	12.0	1.97	2.91
2 tons rye straw	a	0.93	0.72	2.10	2.30	0.33	2.54	1.40	31.0	2.00	4.81
	b	4.00	1.84	2.00	1.90	0.26	2.14	3.20	12.5	2.23	3.34
4 tons rye straw	a	0.84	0.57	1.04	2.68	1.60	0.60	4.40	4.0	2.71	2.05
	b	0.96	0.48	2.00	2.26	0.35	0.80	1.70	7.2	1.35	1.90
8 tons rye straw	a	4.00	0.80	1.32	0.90	0.40	1.50	1.10	5.7	1.32	1.89
	b	1.20	0.42	1.60	1.06	0.54	2.94	5.00	5.3	1.67	2.19

* Cylinders 121–140 received 20 gm. $NaNO_3$ or its equivalent in urea at planting, June 9, and this was repeated on July 29.

† No nitrogen.

‡ One extra 10-gm. portion $NaNO_3$.

‖ One extra 10-gm. portion $NaNO_3$ on carrots and corn, June 28.

in good agreement. This, however, is not surprising, inasmuch as the growth of the crops was not always uniform. The averages for the period, however, indicate higher nitrates with no straw and with 1 and 2 tons of straw than with 4- and 8-ton applications.

SUMMARY

Legume and non-legume crops were grown in Sassafras loam in cylinders without added organic matter and with rye straw, cut fine, varying in amounts from 1 ton to 8 tons an acre. The work was started in 1924 and has been con-

tinued to the present time. Straw has been applied annually according to the plan, with the exception of 1925.

Complete fertilizers were used for most of the work, though in certain series nitrogen was entirely omitted and in others extra quantities of nitrogen in the form of nitrate of soda were used.

With the larger applications of rye straw the yields of non-legume crops were frequently less than the yields on check cylinders. This depressed yield with heavy applications of straw did not occur when legume crops were grown. Likewise there was little or no depression when extra applications of nitrate of soda were made.

In 1925, when no rye straw was used, larger yields were obtained in certain cases from those cylinders which had received the heavy application of straw in 1924 than from the check cylinders, thus showing that the injurious effect of the straw was temporary rather than permanent.

The rye straw had little influence on the percentage of nitrogen in the crop.

Seven years of this treatment did have a distinct influence on the soil. Determinations made on samples of soil collected in 1931 show a gradual increase in total nitrogen, organic carbon, and organic matter as the amount of organic matter applied was increased.

With certain exceptions the carbon-nitrogen ratio was not greatly influenced by the 1- and 2- ton applications of straw, but with 4 and 8 tons to the acre a wider carbon-nitrogen ratio was found.

The heavy applications of nitrate of soda have tended to keep the soil reaction near the neutral point. Where no nitrate was used the soil is gradually becoming more acid.

Nitrate determinations made at intervals during the period indicate that an abundance of organic matter may depress nitrate formation.

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PLATE 1

Effect of Heavy Applications of Nitrate on Corn

The row of corn on the left received an extra heavy application of nitrate; the row on the right received no nitrate. Cylinders in the immediate foreground (both rows) received the rye straw at the rate of 8 tons to the acre.

THE DEGREE OF HUMIFICATION IN MANURES MEASURED BY THE USE OF HYDROGEN PEROXIDE

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It has been shown by Robinson and Jones (4) that humified organic matter can be distinguished from non-humified by the use of 6 per cent hydrogen peroxide. An account is given in the present paper of the use of this reagent in determining the degree of humification in manures. Different workers have employed different concentrations of the reagent. McLean (2) made a thorough investigation with the reagent in various concentrations in estimating the organic matter in soils. Jones (1) used 6 per cent hydrogen peroxide in determining the degree of humification in farmyard manure. Humified or decomposed organic matter appears to be oxidized or rendered soluble by the reagent while the structural or undecomposed materials remain unaffected. It has been assumed by Jones that such a distinction exists in the case of farmyard manure between the decomposed material and the unaltered fiber of the feces and litter. In the present investigation the manures were obtained by artificial methods and no such assumption is made.

Richardson (3) holds that if a reagent is to be used for effecting a separation between humified and non-humified matter it should have a minimum of action on the unhumified matter. He observes that with most materials the greater part of the effect of hydrogen peroxide is simply a solvent action. This means in effect that[2] water alone can reproduce most of the loss by its solvent action. To test the validity of Richardson's statement simliar samples of manure were treated simultaneously under identical conditions with (*a*) water, (*b*) hydrogen peroxide. The time required for the reaction with H_2O_2 to be completed, i.e. when frothing ceased, was first found. The samples were then treated with water for the same length of time with the same volume as peroxide. This gave a comparison between the solvent action of both H_2O_2 and water and also made evident the further action of the reagent over and above that of water. In each of the representative cases the loss of ash and the loss of organic matter due to extractions with both reagents were also compared.

[1] The author is indebted to Sir John Russell, director of the Rothamsted Experimental Station for placing at his disposal the facilities of the station. His thanks are due to Mr. E. H. Richards, head of the fermentation department and to Dr. S. H. Jenkins for their assistance and advice.

[2] With many materials.

In view of the differences of opinion held regarding the use of 3 per cent or 6 per cent hydrogen peroxide, both strengths were tried with chaffed oat straw and with the same straw rotted in the presence of ammonium carbonate. No appreciable difference was found between the results obtained in both cases. It was therefore decided to use 3 per cent hydrogen peroxide instead of 6 per cent in all the quantitative experiments.

EXPERIMENTAL

Oat straw was rotted under aerobic conditions at 35°C. with initial moisture contents of 60, 70, 80, and 90 per cent for each nitrogenous substance. Each bottle, containing 20 gm. of the air-dry straw, was supplied with 0.2 gm. of nitrogen in the form of inorganic salts such as ammonium carbonate, ammonium sulfate, and sodium nitrate, and organic substances such as peptone, casein, and urea. The bottles were incubated for one month and the contents mixed at frequent intervals. Whenever necessary, moisture was added but the manures were never allowed to become water-logged. At the end of 1 month the bottles were weighed and the moisture contents together with other analytical figures were determined. The loss of dry matter on rotting was then calculated and the extent of the decomposition found.

The total percentage of organic matter was determined by finding the "loss on ignition" on 1 gm. of the well-chopped manure dried at 100°C. The quantity of the manure available for analysis being small, about 1-gm. samples of the same dry manure were used for treatment with hydrogen peroxide. The material was gradually heated to boiling with 100 cc. of 3 per cent peroxide with stirring in beakers of 600 cc. capacity. For this reaction, 100 cc. of the reagent was found to be enough. When the frothing had ceased, which indicated that the reaction was complete, the contents of the beaker were made up to about 250 cc. with hot distilled water and boiled for 20 minutes. The contents were then filtered hot, first by decantation of the supernatant layer of the solution on a tared fluted filter paper. The residue was thoroughly washed with hot water till the filtrate was colorless, when it was finally tranferred to the filter and dried at 100°C. It was then cooled in a desiccator and rapidly weighed, as the material absorbs moisture. The residue and filter paper were ashed together and the ash of the filter paper was deducted. The weight of the organic matter initially present being known, the amount lost by oxidation or by solvent action or from both causes can be obtained by difference. The total loss is obtained by subtracting the residue after H_2O_2 treatment from the weight of the dry manure before its treatment with the reagent. This total loss is always found to be more than the loss in organic matter, as it is likely that some of the inorganic material will dissolve out. The loss of organic matter on 100 gm. of the original material gives the degree of humification.

To test whether the loss due to the peroxide treatment was due to oxidation or to solvent action or to both causes in each of the representative cases, the

hydrogen peroxide extract was evaporated to dryness in weighed silica dishes on a water bath and then dried in a desiccator. The ash in the extract was obtained by ignition. The residue in the peroxide extract minus the ash of this extract gives the organic matter present in the extract. The total loss minus the peroxide residue gives the matter oxidized by the action of peroxide.

For comparing the action of water and peroxide, about 5 gm. of the wet samples were extracted with the same volume of water as peroxide under similar conditions. In the case of water extract direct filtration is slow and hence it was first filtered through a plug of cotton wool, and then in a Buchner funnel on a water suction pump. The residue was well washed with hot water, The filtrate was evaporated to dryness on a water bath, weighed, and the total extract was determined by igniting the dried residue.

To determine how the method worked with manures, three different types, which had been rotted under known conditions, were treated first. One

TABLE 1

Results expressed on 100 gm. of dry manure

	MOISTURE CONTENT	TOTAL O. M.*	O. M. AFTER H_2O_2 TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*per cent*
1	82.2	71.9	23.9	48.0	59.0	66.7
2	83.0	55.2	24.7	30.5	36.8	55.2
3	76.0	56.5	44.2	12.3	22.7	44.2

*O. M. = organic matter in this and following tables.

sample was a highly humified farmyard manure. The second was an artificial farmyard manure made from wheat and bean straw rotted with calcium cyanamide as the added supply of nitrogen, and was fairly well humified. The third was wheat straw alone also rotted with cyanamide. It did not appear to be well humified. The results of the treatment of the three manures with peroxide are given in table 1 and seem to agree with the appearance of the samples. The duplicate determinations agreed closely. The difference between the action of 3 per cent and 6 per cent hydrogen peroxide on undecomposed and decomposed straws is not appreciable, as can be seen from table 2.

The loss of organic matter in the case of undecomposed straw is about 20 per cent in both the treatments and in the case of both artificial manures the average loss amounts to about 30 per cent. As there was no difference in the amount of extractable matter obtained with the two strengths of peroxide, the 3 per cent solution was chosen for further experiments. The only noticeable difference was in the colors of the filtrates and the residues. The color in the case of 6 per cent was paler than in the case of 3 per cent. This color difference can be attributed to the bleaching action of the peroxide.

Table 3 gives the results obtained with 3 per cent peroxide on the various artificial manures.

From a study of the figures in table 3 it can be seen that in general the loss of organic matter after peroxide treatment increases with the increase in the initial moisture content, and the percentage loss of dry matter during incubation. There is a corresponding increase in the apparent degree of humification with the increase in the loss of organic matter. The greater the moisture content of the manure and the greater the degree of rotting as measured by loss in dry weight, the greater is the amount of organic matter removed by the peroxide treatment. It is evident from the figures indicating the total loss

TABLE 2

Straw alone

TREATMENT	TOTAL O. M.	O.M. AFTER TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION	WATER EXTRACT
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
3 per cent H_2O_2	93.56	73.90	19.66	21.85	21.02	12.1
6 per cent H_2O_2	93.56	72.89	20.67	23.20	22.10	12.1

Artificial manure made from straw fermented with ammonium carbonate

MOISTURE CONTENT	LOSS OF DRY MATTER	TREATMENT	TOTAL O. M.	O. M. AFTER TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION	WATER EXTRACT
per cent	*per cent*		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
80.3	36.5	3 per cent H_2O_2	90.12	62.94	27.18	31.9	30.16	21.14
85.0	45.8	3 per cent H_2O_2	87.26	55.64	31.62	38.2	36.00	21.23
86.0	39.2	3 per cent H_2O_2	88.90	50.60	38.30	43.41	43.08	22.23
88.6	44.4	3 per cent H_2O_2	87.50	62.90	24.60	34.52	28.12	29.30
80.3	36.5	6 per cent H_2O_2	90.12	64.73	25.39	30.01	28.17	21.14
85.0	45.8	6 per cent H_2O_2	87.26	55.11	32.15	39.22	36.85	21.23
86.0	39.2	6 per cent H_2O_2	88.90	72.30	.....	.....	.....	22.23
88.6	44.4	6 per cent H_2O_2	87.50	54.60	32.90	39.60	37.60	29.30

due to peroxide treatment and to the water extract that the loss is greater with peroxide than with water extraction. This point is also apparent in table 4 where the residue on evaporation of peroxide extract and its ash content are compared with the residue in the water extract and its ash content. In these estimations all the samples of one particular artificial manure were mixed up as evenly as possible and the extractions were then carried out as given in the foregoing. From a consideration of the figures in columns 4 and 8 the residues in water extract is always greater than in peroxide, whereas the total loss in column 3 is always greater than that in column 8. Total loss minus the residue in peroxide extract gives the matter oxidized by the reagent. The residue in the peroxide minus the ash (column 6) gives the organic matter in the peroxide extract which remains quite unaffected by the reagent, i.e., not

oxidized but only dissolved. The figure of 8.8, which is the organic matter in the resistant form in the peroxide extracts, seems to be of some significance. It is constant in five cases out of seven. This resistant form of organic matter may be compared with McLean's resistant form of nitrogen in the soil organic matter. In the first two cases when the figures are higher than 8.8 the filtrate was turbid. This turbidity may be due to the presence of a special type of

TABLE 3

MOISTURE CONTENT	LOSS OF DRY MATTER	TOTAL O. M.	O. M. AFTER TREATMENT	LOSS OF O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION	WATER EXTRACT
per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Straw rotted with $(NH_4)_2SO_4$							
76.54	30.1	88.98	72.70	16.28	22.90	18.30	17.94
80.70	32.5	88.45	63.8	14.65	30.68	16.53	20.50
83.30	31.6	88.52	69.5	19.02	30.51	21.50	20.84
85.25	30.7	88.86	65.21	23.65	29.75	26.61	19.84
*Straw rotted with $NaNO_3$**							
84.80	52.8	78.68	35.85	42.83	57.94	54.44	44.36
86.70	52.3	77.90	33.15	44.75	62.70	57.45	62.10
Straw rotted with H_2O							
81.75	30.0	89.42	73.25	16.17	21.27	18.08	12.93
Straw rotted with peptone							
83.30	39.5	88.38	61.05	27.33	32.53	30.92	21.53
84.42	44.1	87.32	58.84	28.48	34.99	32.61	26.90
Straw rotted with casein							
82.9	41.8	87.60	54.10	33.50	39.33	38.24	27.20
83.6	43.0	85.70	54.70	31.00	38.33	36.20	28.90
Straw rotted with urea							
80.0	32.5	86.95	68.40	18.55	26.70	21.34	19.30
80.5	34.0	88.74	62.40	26.34	32.00	29.46	25.30

* This sample rotted for 45 days; other samples for 30 days only.

organic matter containing a large amount of carbohydrate material or the residues from the fungi which were seen to grow very profusely in both cases. The extraordinarily high figures in the case of sodium nitrate are no doubt due to the high degree of rotting, because the straw was rotted for over 1½ months as compared with 1 month in all the other cases. A comparison of the sodium nitrate manure with the farmyard manure, which was also well rotted, shows that the amount of organic matter after peroxide treatment and matter oxidized in each case respectively are of the same order. The quantity of

organic matter in the water extract is decidedly higher than that in the peroxide extract. Hydrogen peroxide also extracts inorganic material but the ash content of the water extract is, in general, higher than that of the peroxide. The extractive properties of peroxide and water are further compared in table 5. Table 6 gives the action of peroxide on the manures extracted with alcohol.

TABLE 4

Comparison of residue on evaporation of peroxide extract and its ash content with residue in water extract and its ash content

SUBSTANCE USED FOR ROTTING THE STRAW	INITIAL O. M.	O. M. AFTER H_2O_2 TREATMENT	TOTAL LOSS	RESIDUE IN H_2O_2 EXTRACT	MATTER OXIDIZED	ASH IN H_2O_2 EXTRACT	O. M. IN H_2O_2 EXTRACT	RESIDUE IN WATER EXTRACT	ASH IN WATER EXTRACT	O. M. IN WATER EXTRACT
	1	2	3	4	5	6	7	8	9	10
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
$(NH_4)_2CO_3$	88.5	59.85	35.86	20.27	15.59	4.84	15.43	31.0	20.2	10.8
$NaNO_3$	78.3	27.30	68.80	27.40	41.40	14.60	12.80	57.8	25.0	32.8
$(NH_4)_2SO_4$	88.6	66.42	32.19	14.50	17.69	5.89	8.61	21.0	8.8	12.2
Urea	87.7	62.71	32.04	12.87	19.17	4.00	8.87	29.6	7.6	22.0
Peptone	87.8	53.20	40.30	16.35	24.00	7.80	8.55	31.8	9.2	22.6
Casein	86.9	56.30	36.90	15.30	21.60	6.47	8.83	27.2	7.1	20.1
Farmyard manure*	71.9	23.11	61.28	20.28	41.00	11.43	8.85	31.08	11.08	20.0

* Farmyard manure used alone.

TABLE 5

Extractive properties of peroxide and water

	LOSS ON 100 GM. OF THE DRY MANURE AFTER						NET LOSS DUE TO PEROXIDE TREATMENT		
	A. Water extraction			B. Peroxide extraction			B − A		A − B
	Total loss	Organic matter loss	Ash loss	Total loss	O. M. loss	Ash loss	Total loss	O. M. loss	Ash loss
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Straw	12.1	9.1	3.0	21.9	19.7	2.2	9.8	10.6	0.8
Straw rotted with $(NH_4)_2CO_3$	31.0	10.8	20.2	36.5	30.0	6.5	5.5	19.2	13.7
Straw rotted with $(NH_4)_2SO_4$	21.0	12.2	8.8	28.0	18.0	10.0	7.0	5.8	....
Straw rotted with $NaNO_3$	57.8	32.8	25.0	61.0	43.5	17.5	3.3	10.7	7.5
Straw rotted with H_2O	13.0	7.1	4.9	21.3	16.2	5.1	8.3	9.1	....
Straw rotted with peptone	31.8	22.6	9.2	33.5	27.7	5.8	1.7	5.1	3.4
Straw rotted with casein	27.2	20.1	7.1	38.5	32.2	6.3	11.3	12.1	0.8
Straw rotted with urea	29.6	22.0	7.6	29.3	22.4	6.9	....	0.4	0.7
Farmyard manure	31.08	20.0	11.08	59.0	40.0	19.0	28.0	20.0	....

It will be seen, in comparing the average figures for loss in organic matter, total loss, and degree of humification in the various columns in tables 1, 2, and 3 with the corresponding ones in table 6, that those in tables 1, 2, and 3 are in most cases lowered by alcoholic extraction. Alcohol removed some of the organic and inorganic matter from the manures.

The degree of humification thus appears to be a useful measure of the decomposition undergone by any one kind of plant material under different treatments. It must not be regarded as an infallible guide to the value of organic manures in general; still less as an index of the biological availability of the end products.

TABLE 6

Action of peroxide on manures extracted with alcohol

	TOTAL O. M.	O. M. AFTER H_2O_2 TREATMENT	LOSS IN O. M.	TOTAL LOSS	DEGREE OF HUMIFICATION
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Straw	95.95	80.12	15.83	16.81	16.50
Straw rotted with $(NH_4)_2CO_3$	90.32	69.93	24.39	24.48	27.00
Straw rotted with $(NH_4)_2SO_4$	87.10	72.75	14.35	22.48	16.48
Straw rotted with $NaNO_3$	81.20	51.90	21.30	34.58	26.23
Straw rotted with peptone	89.45	49.42	40.03	44.04	44.76
Straw rotted with casein	87.95	65.73	22.22	27.17	25.27
Straw rotted with urea	92.00	62.43	29.57	33.03	32.14
Straw rotted with H_2O	92.99	93.20	.....	20.85	.....
Farmyard manure	37.00	28.80	8.20	22.10	52.20

SUMMARY

The action of 3 per cent and 6 per cent hydrogen peroxide on artificial manures has been studied and it has been found that there is not much difference in the action of the two concentrations of this reagent. Peroxide attacks undecomposed straw to a certain extent.

Artificial manures can be arranged in order of rotting according to the figure for apparent degree of humification derived from loss in weight due to extraction with H_2O_2. Higher initial moisture content in a series of artificial manures results in a greater degree of humification.

In comparing the action of peroxide and water on straw and manures of different origin it has been found that (*a*) the effect of peroxide is more than a solvent action such as is the case with water, (*b*) the water extract contains more organic matter than the peroxide extract, (*c*) water appears to extract more inorganic substance than peroxide, (*d*) the amount of organic matter in the peroxide treatments is generally constant whereas that in the water shows greater variation.

In a series of artificial manures made from straw and various sources of nitrogen the degree of humification could be arranged in the following order,

proceeding from the highest to the lowest: {$NaNO_3$ and $(NH_4)_2CO_3$}, casein, peptone, urea, $(NH_4)_2SO_4$.

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SOME OBSERVATIONS ON BASE EXCHANGE IN ORGANIC MATERIALS[1]

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Although the study of the base exchange phenomenon in mineral soils has been carried to a high degree of attainment, it is only recently that any material progress in the study of base exchange in organic materials has been reported.

Observations and limited studies of this problem were made by several early workers. Rautenberg (14), in 1862, observed base exchange in forest humus; Heiden (5), in peat and various peat preparations; and Eichorn (3), in peat and calcium humate. König (7), in 1882, published a paper giving a review of the work done up to that time, and also reported a long series of experiments which he performed determining the absorption of acids, salts, and bases. He concluded that the absorption process was chemical in nature.

Van Bemmelen (1), continuing his studies of mineral colloids to include humic substances, showed that they form adsorption complexes with acids, salts, and especially bases. These are not, he pointed out, ordinary chemical compounds; they are adsorption compounds of various proportions, depending upon such factors as concentration, temperature, and the nature of the gels and solutions concerned.

An observation which is believed to be of particular significance in the light of the results given later in this paper was reported by Witz (25) in 1882–83. While examining cotton fabrics which had been accidentally overbleached, he observed that the edges of the resulting holes had a strong affinity for basic dyes. The product could be reproduced by the use of various oxidizing agents and was found to contain less carbon and more oxygen than normal cellulose and was given the name "oxycellulose."

It appears, however, that until quite recently there had been no systematic study of this whole problem. The rapid advance in fundamental knowledge of the chemical structure of plants and its relation to the resulting decomposition products has stimulated work along all lines of soil organic matter. Odén (12) has made an extensive study of humus and humus complexes, particularly from the physico-chemical standpoint. He has regarded the humic substances as true acids. A comprehensive review of this subject of soil organic matter, together with an extensive bibliography, has been published by Waksman (18).

Burgess and McGeorge (2) began working on base exchange in soil organic material while studying soil zeolites. Since then McGeorge (8, 9) has published further results of his investigations. He has pointed out the relatively high replacement capacity of the ligno-humate fraction; the formation of synthetic humus, having replacement power, from xylan, sucrose,

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[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and bacteriology. The data are those presented in a thesis submitted to Rutgers University in partial fulfilment of the requirements for the degree of doctor of philosophy, 1930.

[2] The writer wishes to express his appreciation to Dr. Sante Mattson, of this laboratory, for suggesting the problem and for his many helpful suggestions and criticisms offered during the progress of the investigation.

and cellulose; the probable lack of relationship between the nitrogenous or protein fractions and base exchange; the replacement capacity of raw plant material (alfalfa); and the rapid increase in replacement capacity with decomposition. He has concluded that the lignin or ligno-humate material is most active in base exchange, but qualifies this with the necessary statement that because of the variability in the chemical composition of lignin, and the various forms of lignin-carbohydrate linkages, the replacement capacity of materials of plant origin is not a direct function of the lignin content. He believes "the exchange capacity, both in lignin and ligno-humate is a function of the phenolic hydroxyl groups in the molecule.—As the carbohydrates are removed by chemical and biological reactions,—the phenolic hydroxyl groups are rendered free to act and the exchange capacity of the complex increases accordingly."

Mitchell (11) carrying on somewhat similar investigations also concludes that lignin, or a derivative of very similar nature, is the constituent responsible for the base exchange reactions of the ligno-humate fraction of the soil organic matter.

METHODS

In determining the base exchange in the following experiments, the material was treated with 400 cc. of 0.2 *N* barium acetate solution, leached twice with *N* barium chloride solution, washed with distilled water until no test for chlorides was observed, and then leached with 400 cc. of *N* ammonium chloride solution, and the replaced barium determined in the filtrate. The samples varied from 1 to 5 gm., dry basis. The moisture and ash contents were determined on separate samples.

The chemical treatments used were as follows:

Hydrolysis by treatment with 80 per cent sulfuric acid, 10 cc. per 1 gm. of material, in the cold for 2 hours. The acid then diluted with 15 volumes of distilled water and boiled for 3 hours under a reflux condenser [see Fred and Waksman (4)]. This method will be referred to as "hydrolysis treatment."

Treatment with 80 per cent sulfuric acid, 10 cc. per 1 gm. of material, in the cold for 2 hours. The acid then diluted with 16 cc. of distilled water per 10 cc. of 80 per cent acid used and boiled under a reflux condenser for 3 hours. This method will be referred to as "strong acid treatment."

Treatment with sulfuric acid, specific gravity 1.84, 100 cc. per 10 gm. of material. No heat is applied although some heat may be generated during the reaction. At the end of 3 days the mixture is poured into 600 to 1,000 cc. of distilled water [see Tschumanow (16)]. This will be referred to as "concentrated sulfuric acid treatment."

Treatment with 10 per cent sodium hydroxide solution, 10 cc. per 1 gm. of dry material, under pressure at 120° to 130° for 2 hours. Three volumes of hot distilled water are added and the residue filtered off. The dark colored liquor is treated while hot with hydrochloric acid in slight excess to precipitate the dispersed fraction [see Powell and Whittaker (13)]. This procedure will be referred to as "extracted with 10 per cent sodium hydroxide." The residue will be known as "non-dispersible residue," and the hydrochloric acid precipitate as the "dispersed fraction."

Oxidation by chlorine to give oxycellulose. Ten grams of material is added to a boiling solution of 50 gm. of potassium chlorate in 1,000 cc. of water, and 42.5 cc. of 35 per cent hydrochloric acid is gradually added. The mixture is held at the boiling point for 1 hour [see Vignon (17)]. This will be referred to as "oxidation by chlorine."

Oxidation by potassium permanganate. Thirty grams of material is treated with 600 cc. of 6.5 per cent sodium hydroxide solution and shaken until a pulp is formed, which is then thinned with water, made acid with sulfuric acid, filtered off by suction, and washed with

water. The moist pulp is suspended in 600 cc. of 7.5 per cent sulfuric acid solution and rapidly stirred mechanically. Twelve grams of potassium permanganate dissolved in 7.5 per cent sulfuric acid is slowly added by means of a dropping funnel, 1 to 2 hours being taken for the addition. The solution becomes decolorized after several hours. The brown precipitate is then filtered off, suspended in dilute sulfuric acid, decolorized by hydrogen peroxide, and washed with water until free of acid and manganese sulfate. It is dried at a temperature not exceeding 40°C. [see Knecht and Thompson (6)]. This will be referred to as "oxidation by permanganate."

Ether extraction, carried out in the usual way by means of Soxhlet extractors.

THE BASE EXCHANGE CAPACITY OF ORGANIC MATERIALS

In order to formulate a classification of a group of various organic materials from the standpoint of base replacement, a series of determinations was made on these materials. All of the substances studied were first ground to pass a 2-mm. sieve or finer.

The "Natural Humus" and "Hyper-Humus," both of these being trade names, are black peats from northwestern New Jersey dug for agricultural use and partially air dried. The German peat moss was of the usual quality imported for stable use. The leaf mold was obtained in southern New Jersey and was a forest ground covering. The sphagnum moss was growing when gathered about 6 months prior to the time that it was used in this experiment and had been thoroughly air dried. The Michigan peat was largely wood in various stages of decomposition. The brown rot was a sponge-like mass obtained from the base of a large living black oak tree near Princeton, New Jersey. The oak leaves were dead, but still attached to the twigs of the tree when gathered. The Barr Bog peat was from Michigan and consisted of only partially decomposed swamp growth. The bagasse was a by-product from the manufacture of "Cellotex," a commercial insulating wall board, and was artificially dehydrated. The shavings were of hardwood and of the type commonly employed as litter in stables.

The results of the base exchange determinations on these various materials are given in table 1.

Table 1 shows that the degree of decomposition and the base exchange are more or less correlated, the materials such as the peats having a high base exchange and the fresh materials such as straw and wood shavings having little or none. However, this generalization does not hold in all cases. The sphagnum moss and oak leaves although entirely undecomposed, showed a relatively high base exchange.

Effect of decomposition on the base exchange capacity of organic materials

In order to determine what magnitude the effect of decomposition might assume, and the rapidity with which it would become effective, quantities of ground straw and dehydrated cow manure (with peat moss litter), inoculated with a few cubic centimeters of soil extract and kept moist, were allowed to decompose under aerobic conditions. The results of the base exchange determinations are presented in table 2.

The gradual increase in the base exchange of the straw as decomposition

progressed is particularly interesting, since so little base exchange is apparent in the original material. According to Waksman and Tenney (22) the aerobic decomposition of straw is accompanied by a gradual disappearance of the cellulose and hemi-celluloses and an accumulation of the lignin. Accumulated

TABLE 1

Base exchange in organic materials

MATERIAL	BASE EXCHANGE PER GRAM DRY WEIGHT	ASH (DRY BASIS)
	m.e.	*per cent*
Peats and Humus:		
"Natural Humus"	1.73	25.48
German peat moss	1.43	1.24
"Hyper-Humus"	1.39	11.58
Leaf mold	1.18	21.68
Michigan peat	1.07	3.27
Bar bog peat	0.66	8.47
Plant materials:		
Sphagnum moss	1.12	5.72
Oak leaves	0.95	3.31
Bagasse	0.13	3.30
Rye straw	0.12	4.97
Wood shavings	0.00	0.70
Miscellaneous:		
Brown rot	1.07	2.83
Cellulose (filter paper)	0.00	0.18

TABLE 2

Base exchange in decomposing organic materials

TIME	BASE EXCHANGE PER GRAM DRY WEIGHT	
	Straw	Manure
	m.e.	*m.e.*
Beginning	0.12	0.73
3 weeks	0.22	1.03
8 weeks	0.30	1.09
14 weeks	0.33	1.11
24 weeks	0.38	1.45
36 weeks	0.59	1.67

lignin, together with synthesized microbial cell substance, is believed by Waksman (18) to make up a large part of the natural soil humus.

Base exchange in organic materials as influenced by chemical treatments

It has been shown that natural decomposition processes intensify the base exchange in organic materials. These processes, however, are slow, and so

many different processes are at work simultaneously that even by analysis of the end products it is impossible to say just what compounds or complexes are present at any given time. In order to study this question under somewhat better controlled conditions, a series of chemical treatments was selected and various organic materials, both natural plant materials and pure substances,

TABLE 3

Base exchange in organic materials as influenced by chemical treatments

TREATMENT	STRAW	CELLULOSE	WOOD SHAVINGS	SPHAGNUM MOSS	HUMUS	"NATURAL HUMUS"	BROWN ROT
	m.e.	*m.e.*	*m.e.*	*m.e.*	*m.e.*	*m.e.*	*m.e.*
No treatment	0.12	0.00	0.00	1.12	2.65	1.73	1.07
Ether extraction	0.13	....	0.00	....	....	....	....
Hydrolysis treatment	0.10	....	0.20	1.40	1.96	1.65	1.06
Dry heat, 300°C	0.27	....	....	....	....	....	....
Strong acid treatment	1.02	....	0.52	1.62	1.75	1.46	1.09
Extracted with 10 per cent sodium hydroxide:							
Non-dispersible residue	0.00	....	0.33	1.37	....	2.39	....
*Hydrolysis treatment	0.00	....	....	....	....	....	....
Strong acid treatment	0.88	....	....	....	....	....	....
Oxidized by chlorine	0.24	....	....	....	....	....	....
Dispersed fraction	1.10	....	0.48	1.42	....	2.65	1.68
Hydrolysis treatment	0.47	....	....	....	....	....	....
Strong acid treatment	0.36	....	....	....	....	2.43	....
Oxidation by chlorine	0.59	0.18	....	....	1.91	....	1.31
Extracted with 10 per cent sodium hydroxide:							
Non-dispersible residue	0.39	....	....	....	....	....	....
Dispersed fraction	1.14	....	....	....	....	....	....
Oxidation by permanganate	....	0.10	....	....	....	....	....
Extracted with 10 per cent sodium hydroxide:							
Non-dispersible residue	....	0.16	....	....	....	....	....
Dispersed fraction	....	0.33	....	....	....	....	....
Reprecipitated from Schweitzer's reagent	....	0.00	....	....	....	....	....
Concentrated sulfuric acid treatment	....	1.30	....	....	....	....	....
Extracted with 10 per cent sodium hydroxide:							
Non-dispersible residue	....	3.71	....	....	....	....	....

* The sub-treatments were applied to the residues of the respective original treatments.

were subjected to them. These treatments have been described under *Methods*. All of the results, recorded in table 3, are given as base exchange capacity, milli-equivalents per gram of dry material *remaining after the treatment.*

The materials used have all been described with the exception of the cellulose, which was Whatman no. 2 filter paper containing 0.0029 gm. ash per 15-cm.

sheet, equivalent to approximately 0.18 per cent ash; and the humus, which was prepared by Mattson, who has given the method of preparation elsewhere (10).

DISCUSSION

If the classification of plant material constitutents as arranged by Waksman and Tenney (21) are accepted as a basis for consideration of the data presented, there are the following groups:

Ether-soluble substances: oils, fats, and waxes. It is probable that when aqueous salt solutions are used, the base exchange cannot be associated with this group in general. Furthermore, these substances are comparatively resistant to decomposition by microörganisms (19), and table 2 shows an increase in base exchange in straw almost as soon as decomposition begins. It is possible, however, that there may be some relationship of this group under certain conditions.

Water-soluble substances, including the readily dispersible colloidal substances: sugars, tannins, pectins, starches, amino acids, and other organic acids. The true water-soluble substances obviously cannot be concerned. The others have not been studied, but as McGeorge (9) points out there is a possibility that the pectins possess base exchange properties. Preliminary experiments in this laboratory also indicate the possibility of base exchange in alumino-tannate complexes.

Hemicelluloses. These are principally lyophyllic colloids, present in most plant material, either fresh or decomposed. Tenney and Waksman (15) give the hemicellulose content of rye straw as 21 per cent and of oak leaves 13 per cent, and the hemicellulose content of peat has been shown to vary from 5 to 17 per cent (20). No intensive study seems to have been made of this group of substances from the standpoint of base exchange, but Mitchell (11) concludes from his work that they do enter into the reaction.

Cellulose. No base exchange was observed in untreated cellulose or reprecipitated cellulose (table 3), nor has any mention of such observations by other investigators been seen. McGeorge (9) has reported a base exchange capacity of 0.4 m. e. per gram of cellulose after treatment with 10 per cent hydrochloric acid on the steam bath, the resulting product being a dark brown mass. A considerably greater base exchange capacity was found in this laboratory when filter paper was treated with concentrated sulfuric acid, as shown in table 3. The resulting product was black, and became hard and lustrous upon drying. According to Tschumanow (16) the composition is 62 per cent carbon, 5 per cent hydrogen, and 33 per cent oxygen, corresponding to the formula $(C_2H_2O)_n$ and approaching "ulmic acid" in composition. Here then is a material derived from pure cellulose having much the appearance of a humic substance, being colloidal in nature, and having a relatively high base exchange capacity. A fraction may be dispersed in strong sodium hydroxide solution under pressure and reprecipitated by hydrochloric acid, the method for extracting lignin. The non-dispersible residue exhibits a very high base exchange capacity.

Cellulose oxidized by chlorine or permanganate also has been shown to possess a base replacement capacity. Since oxidation is probably the most common of the natural chemical processes, it would seem reasonable to suppose that, under conditions unfavorable to the complete breaking down of the cellulose, oxycellulose might result. Winogradsky (23, 24) has mentioned isolating several forms of cellulose decomposing bacteria which gave oxygen-saturated products resembling soil humus in being colloidal, nitrogenous, resistant to further bacterial attack, and soluble in dilute alkalies. He believed that "they remain for a long time components of the organic colloids" of the soil. These products were quite possibly mixtures of oxycellulose and bacterial cell substance.

Lignin. Undoubtedly this substance is largely concerned in base exchange in natural

organic materials. McGeorge (9) and Mitchell (11) have both concluded that this is the most active of all of the soil organic matter fractions. The results given here also lead to that general conclusion. However, it should be borne in mind that lignin varies in composition in different species of plants and even in different parts of the same plant. Furthermore, the methods of isolation involve such drastic treatments that it is impossible to obtain lignin unchanged from its natural state. This is true not only of its chemical structure but also of its base exchange capacity, as is shown by the difference between "alkali" lignin and "acid" lignin obtained from straw. However, it seems logical to assume that lignin is largely responsible for base exchange in natural organic materials.

These few observations recorded in the accompanying tables, while not extensive enough to be used as any definite basis for hypotheses, do indicate, it is felt, the trend which further investigations should follow to solve this problem. It is apparent that no one substance is wholly responsible for base exchange in organic materials. Furthermore, the chemical treatments used to isolate the various plant material fractions are so drastic as to preclude the assumption that those isolated are identical in structure with those in the plant before isolation. Probably complex combinations of two or more substances, as well as intermediate degradation products, enter into the reaction. It is felt that no real progress can be looked for by simply making a large number of base exchange determinations on these innumerable substances.

Considering again the results obtained with cellulose (table 3), for example, it is shown that untreated cellulose, as represented by finely divided filter paper, has no base exchange capacity. Reprecipitated cellulose has none. Oxidized cellulose, obtained by two different methods, shows some; and cellulose treated with strong sulfuric acid and then strong alkali has a base exchange capacity greater than natural or purified humus. Pure cellulose is the only substance making up this exchange complex, but it has been so acted upon by the reagents used that it is no longer recognizable, and in truth is no longer cellulose. In the turmoil its structure has been rearranged from one having no base exchange capacity to one having a very great one.

The answer must be sought further than simply as to the identity of the substances making up any particular material. The chemical structure must be studied. It is strongly believed that free valences are the determining factor. Free carboxyl or hydroxyl groups or free hydrogens should be sought as determining the base exchange capacity. No doubt other groups may also be involved. Before trying to determine in each of innumerable individual cases with what particular substance the base exchange property is associated, it would appear more logical, by using materials of known chemical structure, to determine to what radicals this phenomenon is attributable. Then it would be but a step to postulate the occurrence of base exchange under certain definite conditions.

Natural organic materials, and particularly soil organic matter, are in a dynamic state, building up on one side and tearing down on the other. Under these unstable conditions, it must be concluded that base exchange capacity is determined by the chemical structure existent under the conditions of and at

the moment of the determination, and is not simply a property of some particular substance present.

SUMMARY

Various natural organic materials were shown to have considerable base exchange capacities.

Decomposition by natural processes increased the base exchange in straw and manure.

The base exchange of several organic materials was markedly altered by certain chemical treatments.

It is concluded that under the present methods of drastic chemical treatments required for the isolation of the various fractions of organic materials, the property of base exchange should be assigned to certain groups such as hydroxyl or carboxyl, rather than to specific chemical substances.

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LYSIMETER STUDIES: II. THE MOVEMENT AND TRANSLOCATION OF SOIL CONSTITUENTS IN THE SOIL PROFILE

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Notwithstanding the vast volume of work reported on the physical, chemical, and biological behavior of the soil, not much is known about the movement and translocation of the elements in it. One of the fundamental objects of lysimeters has been the study of the outgo of the important plant food elements, the so-called losses which have troubled the soil fertility worker ever since Liebig promulgated his famous mineral theory. And even before Liebig's time the lysimeter was used to evaluate the principle of plant growth by checking and analyzing the leachings.

The comparatively slow progress made in constructing the picture of what is going on in the soil has been due to the inadequate appreciation of what a soil is, its complex constitution and make-up, and its behavior as a natural unit. Lysimeters of the filled-in type have been of limited help in unraveling the secrets of the movement of soil constituents. Their artificial make-up precludes the use of data obtained on leachings from them for the interpretation of phenomena which occur in a natural soil.

With the introduction of the new type of lysimeters at the New Jersey station (3) adopted for the study of soils in their natural habitus a promising approach has been made toward obtaining leachings which represent the natural behavior of the soil.

CONDUCTIVITY AND REACTION OF LEACHINGS[3]

A_1 horizon

Soil reactions hinge on the activity of the inorganic and organic electrolytes formed in the process of decomposition of the mineral and organic constituents of the soil by chemical and biological agencies. The inorganic electrolytes as

[1] ERRATUM: In the author's paper "Lysimeter Studies: I. Moisture Percolation through the Soil Profile, "*Soil Sci.* (1932) 34: 142, reference (9) should read: *Gemmerling, U. V.* 1922 *On the moisture regime of podzol soils on the basis of data from lysimeters (Russian). Trudui Moskor. Sel'sko-Khoz. Oblas. Stan. Bul. 1: 88–95.*

[2] Journal Series paper of the New Jersey Agricultural Experiment Station, department of agronomy.

[3] For a detailed description of the lysimeter set-up, methods of sampling and analyses the reader is referred to the first paper of this series (3).

a rule are highly dissociated in water and exhibit a high conductivity, especially with an increase in concentration, as measured by the Kohlrausch apparatus. Organic acids in the presence of their salts behave in a similar manner. Conductivity measurements may therefore serve as indexes of the concentration of solutes present.

Tables 1 and 2 present in terms of reciprocal ohms the conductivity of the leachings from the various horizons in the soil profile for two consecutive

TABLE 1

Conductivity and reaction of leachings for 1929–1930

NUMBER OF LEACHING	DATE OF COLLECTION	LYSIMETER UNDER HORIZON A_1			LYSIMETER UNDER HORIZON A_2			LYSIMETER UNDER HORIZON B_1		
		Quantity collected	Conductivity*	Reaction	Quantity collected	Conductivity	Reaction	Quantity collected	Conductivity	Reaction
		liters	*mhos*	*pH*	*liters*	*mhos*	*pH*	*liters*	*mhos*	*pH*
	1929									
1	6/22	1.065		4.8	0.165		4.8			
2	6/24	0.510		4.8	0.00					
3	7/30	1.400		4.8	0.00					
4	8/15	0.755		4.8	0.00					
5	9/9	4.740	114×10^{-6}	4.8	2.400	121.8×10^{-6}	4.8	0.050	149×10^{-6}	5.4
6	9/18	0.470		4.8	0.00					
7	10/3	3.440	159×10^{-6}	5.4	0.210	141.1×10^{-6}	5.6			
8	10/23	0.930	257×10^{-6}	6.2	0.00					
9	11/5	0.390	243×10^{-6}	6.4	0.00					
10	11/20	0.135	251×10^{-6}	6.4	0.00					
11	12/20	1.180	155×10^{-6}	4.8	0.090	232×10^{-6}	5.0			
	1930									
12	2/18	3.435	102×10^{-6}	4.6	1.265	112×10^{-6}	4.8			
13	3/11	0.250	119×10^{-6}	4.8						
14	5/17	0.100	121×10^{-6}	4.6						
15	6/11	2.200	78×10^{-6}	4.8	1.395	135×10^{-6}	4.8	0.050	168×10^{-6}	5.4

Total leachings 21.000.

* The conductivity has been determined by the Kohlrausch apparatus at a temperature between 22 and 23°C.

years. Figure 1 gives a graphic illustration of the tendencies in the conductivity of the leachings from A_1 for the two consecutive years.

There is a remarkable similarity between the two curves for 1929–1930 and 1930–1931, which points to a yearly periodicity in the type and content of electrolytes released in the soil. The conductivity takes an upward turn in the fall just about the time when the leaves are heavily shed. It indicates that at that time the soil becomes enriched with highly dissociated inorganic electrolytes. Apparently the soluble inorganic salts present in the freshly fallen leaves are washed out by the fall rains, augmenting the salt content of

TABLE 2

Conductivity and reaction of leachings for 1930–1931

NUMBER OF LEACHING	DATE OF COLLECTION	LYSIMETER UNDER HORIZIN A_1			LYSIMETER UNDER HORIZON A_2			LYSIMETER UNDER HORIZON B_1			LYSIMETER UNDER HORIZON C		
		Quantity collected	Conductivity	Reaction	Quantity collected	Conductivity	Reaction	Quantity collected	Ccnductivity	Reaction	Quantity collected	Conductivity	Reaction
		liters	*mhos*	*pH*	*liters*	*mhos*	*pH*	*liters*	*mhos*	*pH*	*liters*	*mhos*	*pH*
	1930												
16	7/10	1.300	94×10^{-6}	4.8									
17	7/23	1.300	83×10^{-6}	4.8									
18	8/16	0.080	90×10^{-6}	4.8									
19	8/24	3.350	161×10^{-6}	4.8									
20	9/17	0.350	352×10^{-6}	6.1									
21	10/16	0.325	345×10^{-6}	6.4									
22	10/29	0.608	344×10^{-6}	6.4									
23	11/6	1.455	213×10^{-6}	5.4									
24	11/19	2.420	200×10^{-6}	4.8									
25	12/30	4.090	167×10^{-6}	4.6	1.870	152×10^{-6}	4.6	0.160	135×10^{-6}	6.8	0.355	113×10^{-6}	7.4
	1931												
26	2/19	4.100	151×10^{-6}	4.6	1.200	120×10^{-6}	4.8	0.050	123×10^{-6}	4.9	0.080	103×10^{-6}	4.9
27	3/9	1.770	118×10^{-6}	4.8	0.250	123×10^{-6}	4.8						
28	3/30	3.305	117×10^{-6}	4.8	0.910	203×10^{-6}	4.6	0.025	180×10^{-6}	5.0			
29	4/2	0.665	126×10^{-6}	4.6									
30	4/12	0.505	143×10^{-6}	4.8									
31	5/15	0.700	128×10^{-6}	4.8									
32	5/24	0.475	140×10^{-6}	4.8									
33	6/11	1.950	145×10^{-6}	4.8				0.040	607×10^{-6}				
34	6/18	0.475	155×10^{-6}	4.8	0.045	142×10^{-6}	4.8	0.020	74×10^{-6}				

Total leachings 29.223.

the leachings which is manifested in the conductivity. The high conductivity does not last long. Soon a drop takes place. It is of interest that the rise in conductivity corresponds to low percolation, which means a high concentra-

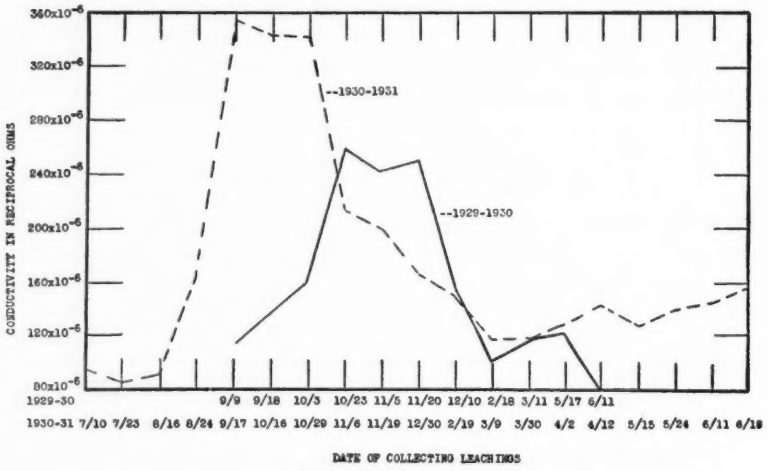

FIG. 1. CONDUCTIVITY CHANGES IN LEACHINGS FOR 1929–1930 AND 1930–1931

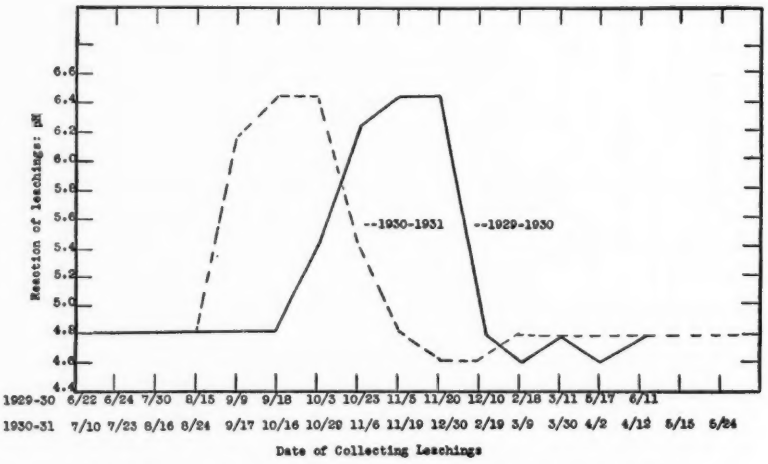

FIG. 2. REACTION CHANGES IN LEACHINGS FOR 1929–1930 AND 1930–1931

tion of solutes, whereas the drop in conductivity corresponds to a high percolation, which means a low concentration of solutes.

Figure 2, illustrating the relation of the H-ion concentration of the leachings in A_1 to the time of collecting them, shows that the rise in pH corresponds to

the rise in conductivity and similarly the drop in pH corresponds to the drop in conductivity.

The rise in pH is due to an increase in OH ions and a suppression of the H ions, which means that the salts released from the freshly fallen leaves consist largely of bases: K, Na, Ca, Mg. Lack of material precluded any determinations for the alkali bases, but the data in tables 3 and 4 clearly show that just during the period of the rise in conductivity the concentration of the alkaline earth bases goes up.

A significant fact about the pH values of the leachings from A_1 is the similarity in periodicity and in the parallelism of the curves (compare figure 2 with figure 1) to those of the conductivity. Of course, the increased base content of the leaching is responsible for the rise in the pH values. A similar observation on the increase of the pH in soils during the fall has been made by Fehér (1) in his study on the microbiological activities in forest soils. There is another still more significant fact about the pH of the leachings: except for the brief period during the fall the pH of the leachings is practically constant—between 4.6 and 4.8. And yet the pH of the soil material in the A_1 horizon ranges between 5.1 and 5.2. No explanation suggests itself at this time to account for this peculiarity.

A_2, B_1, and C horizons

Because of the lack of any appreciable number of leachings from A_2, still fewer from B, and only two from C, the few conductivity measurements do not warrant any definite conclusions. It seems that the tendency is for the conductivity in A_2 to be about the same as in A_1, to increase in B, and to decrease in C. This, however, is not at all true for the leachings of 1930–1931.

From theoretical considerations about the podzol process of soil formation there should be more electrolytes under A_2 than under A_1 thereby tending to increase the conductivity. On the other hand the leachings from B should be lower in electrolytes because of the new formations in this horizon. But the soil under consideration is not a mature podzol and therefore some of the reactions might not be typical of a podzol. With the accumulation of more data on the leachings some of the puzzling points might be cleared up and thereby reveal new facts about the podzolization process.

As to the pH values of the leachings from these horizons, as shown in tables 1 and 2, it is clear that an increase takes place in B, where the bases are retained—permanently or temporarily—because of the characteristic property of this horizon to accumulate basic materials and to be less unsaturated than the horizons above.

MOVEMENT OF SOIL CONSTITUENTS THROUGH THE PROFILE

A_1 horizon

The method of analyses pursued is as follows: 500 to a 1,000 cc. of the leachings are evaporated in platinum dishes, and the residue is dried at 105°C.

TABLE 3

Chemical constituents which percolated through A_1 (18 cm. from the surface) in 1929–1930

LABORATORY NUMBER OF LEACHING	DATE OF COLLECTION	LEACHINGS	TOTAL SOLIDS AT 105°C. IN		LOSS ON IGNITION			Ca IN		Mg IN		Cl IN		S IN		R_2O_3 IN		SiO_2 IN	
			100 cc.	Total leachings	100 cc.	Total leachings	Per cent	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings
		liters	*mgm.*	*mgm.*	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	1929																		
1	6/22	1.065	14.5	154.3	6.8	72.42	46.9	0.696	7.41							0.80	8.520	0.20	2.130
2	6/24	0.510	11.0	56.1	4.6	23.46	41.8	0.835	4.26							0.16	0.820	0.24	1.224
3	7/30	1.400	20.7	289.8	10.16	142.24	49.0	1.153	16.148			0.693	9.696	1.632	22.848	0.48	6.72	0.48	6.720
4	8/15	0.755	15.0	113.25	5.80	43.79	38.6	0.994	7.505			0.396	2.990	0.604	4.560	0.333	25.142		
5	9/9	4.740	12.9	611.46	5.72	271.13	44.3	0.736	34.886	0.205	9.717	0.3564	16.893	1.086	51.476	0.380	18.012	0.24	11.376
6	9/18	0.470	10.1	47.47	3.40	15.98	33.6	1.10	5.17			0.2474	1.163	1.099	5.165	0.956	4.492	0.18	0.846
7	10/3	3.440	14.82	509.80	5.29	181.97	35.6	1.183	40.695			0.6185	21.276	1.588	54.627	0.72	24.768	0.373	12.831
8	10/23	0.930	20.4	189.72	7.20	66.96	35.2	1.530	14.229			0.841	7.821	1.840	17.112			0.466	4.334
9	11/5	0.390	21.78	84.94	8.78	34.24	40.3	1.60	6.240									0.610	2.379
10	11/20	0.135	No determinations made																
11	12/20	1.180	15.00	177.0	5.15	60.77	34.3	0.74	8.732	0.437	5.157					0.23	2.714		
	1930																		
12	2/18	3.435	11.02	378.54	2.285	78.49	20.7	0.23	7.90			0.24	8.244					0.161	5.53
13	3/11	0.250	No determinations made																
14	5/17	0.100	No determinations made																
15	6/11	2.200	13.68	300.96	6.06	133.32	44.2	0.17	3.74	0.205	4.51	0.18	3.960			0.20	4.40	0.30	6.6
1. Total.....		21.000	180.90	2,913.34	71.24	1,124.77		10.967	156.915	0.847	19.384	3.572	72.043	7.849	155.788	4.259	95.588	3.250	53.97
2. Average per 100 cc.*.....			15.08	14.21	5.93	5.49		0.914	0.764	0.282	0.272	0.446	0.38	1.308	1.327	0.473	0.606	0.325	0.290
3. Calculated totals†...			2,984.10		1,152.9			160.44		57.12		79.80		278.67		127.26		60.90	
4. Total per acre in grams‡.....			164,125.5		63,409.5			8,824.2		3,141.6		4,389.0		15,326.85		6,999.3		3,349.5	
5. Total per acre in pounds.....			361.5		139.6			19.4		6.91		9.6		33.76		15.41		7.38	

* The average per 100 cc. under the columns "total leaching" was calculated by dividing the respective total constituents by the respective total leachings on which determinations were made.

† To obtain the calculated totals on all the 15 leachings the average per 100 as calculated was multiplied by 21 liters—the total leachings for the year.

‡ The total per acre was calculated by multiplying the figures in 3. by 55,000, the area of the lysimeter being equal to $\frac{1}{55,000}$ acre.

TABLE 4

Chemical constituents which percolated through A_1 (18 cm. from the surface) in 1930–1931

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		liters	*mgm.*	*mgm.*	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	1930																		
16	7/10	1.300	18.90	245.70	12.42	161.42	65.6	0.52	6.76	0.177	2.301					0.48	6.24	0.42	5.46
17	7/23	1.300	12.20	158.60	7.06	91.78	57.8	0.66	8.58	0.161	2.093					0.50	6.50	0.46	5.98
18	8/16	0.080	No determinations made																
19	8/24	3.350	22.08	739.68	12.08	404.68	54.7	0.46	15.41	0.275	9.213	0.12	4.020	1.35	39.225	0.56	18.76	0.26	8.71
20	9/17	0.350										0.06	0.210	3.20	11.200				
21	10/16	0.325																	
22	10/29	0.608	46.20	280.90	23.66	143.85	51.2	1.40	8.51	0.728	4.426	0.16	0.973	2.65	16.112	0.53	3.24	0.13	0.81
23	11/6	1.455	33.04	480.73	15.00	218.25	45.3	0.88	12.80	0.534	7.769	0.145	2.110	2.70	39.285	0.50	7.27	0.12	1.75
24	11/19	2.420	23.60	571.12	7.88	190.69	33.3	0.82	19.84	0.423	10.237	0.100	2.420	1.80	43.560	0.70	16.94	0.28	6.78
25	12/30	4.090	12.30	503.07	5.00	204.45	40.6	0.74	30.27	0.334	13.661	0.600	24.540	0.96	39.264	0.73	29.86	0.16	6.54
	1931																		
26	2/19	4.100	10.60	434.60	4.14	169.74	39.0	0.73	29.93	0.292	11.97	0.540	22.14	1.23	50.43	0.66	27.06	0.20	8.20
27	3/9	1.770	10.18	180.19	3.65	64.61	35.8	0.75	13.28	0.301	5.328	0.580	10.27	1.15	20.355	0.706	12.50	0.106	1.88
28	3/30	3.305	9.42	311.33	3.50	115.68	37.1	0.60	19.83			0.580	19.169	0.88	29.084	0.610	20.16	0.070	2.31
29	4/2	0.665	9.47	62.98	2.52	16.76	26.6	0.63	4.19	0.308	2.048			1.40	9.31				
30	4/12	0.505	10.22	51.61	2.62	13.23	25.6	0.67	3.38	0.350	1.767								
31	5/15	0.700	10.02	70.14	3.72	26.04	37.1	0.31	2.17	0.131	0.917							0.240	1.68
32	5/24	0.475	No determinations made																
33	6/11	1.950	15.80	308.10	9.60	187.20	60.7	0.56	10.92	0.245	4.777							0.213	4.15
34	6/18	0.475	No determinations made																
1. Total.....		29.223	244.03	4,398.75	112.85	2,008.38		9.73	185.87	4.259	76.507	2.885	85.852	17.32	297.825	5.976	148.53	2.659	54.25
2. Average per 100 cc.*.....			17.4	15.9	8.06	7.3		0.695	0.675	0.328	0.316	0.3616	0.400	1.732	1.346	0.598	0.627	0.222	0.206
3. Calculated totals†...				4,646.46		2,133.3			197.255		92.345		116.892		393.341		183.228		60.199
4. Total per acre in grams‡.....				255,555.3		117,331.5			10,849.03		5,078.98		6,429.06		21,633.75		10,077.54		3,310.95
5. Total per acre in pounds.....				562.8		258.4			23.8		11.18		14.16		47.6		22.19		7.29

*, †, ‡ For explanatory legends see table 3.

and then heated to cherry red for loss on ignition. The ash is taken up with HCl, the SiO_2 is stabilized, and the rest of the constituents are determined in the regular way. The data in tables 3 and 4 give a detailed account of the constituents released from the A_1 horizon. An analysis of the data offers many clues as to what is going on in the A_1 horizon, that part of the soil body which in a large measure determines the behavior of the other parts. For this horizon is the potential source of the various constituents which enter into the "blood circulation" (soil solution) of the soil body.

A discussion of each one of the constituents will help to clarify the intricate reactions in their relation to the leachings, seasonal variations, and each one constituent.

Total solids and loss on ignition. The quantity of total solids—in pounds per acre—which percolated through A_1 in 1930–1931 is close to 56 per cent higher than in 1929–1930. This might not be surprising in view of the larger total leachings in 1930–1931—29.223 liters against 21.0 liters in 1929–1930. On the other hand one might have expected that an increase in leachings would dilute the solids, but this was not the case. The average concentration of solids per 100 cc. in the leachings of 1930–1931 increased by 11.8 per cent—15.9 against 14.21 mgm. per 100 cc. of leachings. The cause of such a behavior is, of course, problematic. It will be recalled (3) that the rainfall in 1929–1930 was higher than in 1930–1931—37.26 and 34.14 inches respectively. But the effective precipitation—the amount of rainfall after which leachings percolated through the horizon—was higher in 1930–1931 than in 1929–1930—24.81 and 22.47 inches respectively—, which accounts, as pointed out (3), for the higher total leachings. Evidence was presented to prove that the state of the colloids is probably responsible for the difference in percolation. Whether this has anything to do with the higher concentration of total solids in the leachings of 1930–1931 is not at all clear.

A qualitative analysis of the total solids offers a clue to the probable cause of the apparently anomalous quantitative results. An examination of the percentage of loss on ignition on the total solids reveals the fact that it is higher in 1930–1931 than in 1929–1930: 45.9 and 38.6 per cent respectively. There can be no other reason for such higher loss on ignition except that there was more organic matter in the total solids of the second year's leachings. This means that more organic matter went into circulation in 1930–1931 carrying, of course, also large amounts of inorganic constituents, for humifying and mineralizing reactions go hand in hand. Apparently the environmental conditions for microbiological activities in the soil were more favorable in 1930–1931 than in 1929–1930. There is another way of looking at this qualitative difference of the total solids. As pointed out, they are 56 per cent higher in 1930–1931 than in 1929–1930, but if we calculate the total ash (by subtracting the loss on ignition from the total solids) we find it is only 37 per cent higher, thus 19 per cent increase of the total solids is to be ascribed to the increase in organic matter.

With the increase in quantity of total solids came also the increase in concentration of solutes per unit of solution, as pointed out. And a glance at the columns on the total solids per 100 cc. of leachings shows that this increase is more apparent during the months of October and November. This will help to explain the higher peak in the conductivity curve (fig. 1) of the leachings of 1930–1931 even though the type of curve has remained the same as for the leachings of 1929–1930. Such behavior is in harmony with the conductivity laws established by Kohlrausch.

Calcium and magnesium. The release of bases from the A_1 horizon is true for every type of soil formation. It is the movement and translocation of these bases in the soil profile that differentiate the types of soil formation in the temperate arid and semi-arid regions from the temperate humid region. In the podzol process of soil formation the movement and translocation of these bases are more intense and result in actual losses from the soil body.

A comparison of the losses of bases shows that during the second year the amount of Ca in the leachings was 22.6 per cent higher than during the first year (the difference between 23.8 and 19.4 pounds for the respective years) and the amount of Mg lost was 61.7 per cent higher (the difference between 11.18 and 6.91 pounds). The reason for the relatively higher loss[4] of Mg, as compared with Ca, is not clear.

Both Ca and Mg show the same tendency to increase in concentration during the summer and fall, attaining a maximum concentration in October and November and dropping off during the winter and spring. It may not be out of place to recall again that the highest concentration of the bases corresponds to the highest conductivity and pH. There seems to be some correlation between the quantity of leachings and the concentration of Ca in the leachings. This suggests that we are dealing with a salt of a low solubility product and it might be $CaSO_4 \cdot 2H_2O$.

An interesting point to be noted is that the average concentration of Ca per 100 cc. is higher in 1929–1930 than in 1930–1931. The reverse is true for the Mg.

Chlorine and sulfur. There seems to be no consistent regularity in the chlorine concentration of the leachings at the various seasons of the years. Apparently the chlorine content depends on the prevailing atmospheric condition over the Atlantic seaboard. Some rains being more chlorine, some less.

The high sulfur content in the leachings in the form of sulfates is indicative of the rapid conversion of sulfur compounds into sulfates. Unquestionably it is the oxidation of the sulfur in the organic matter that augments the leachings with sulfates. The higher organic matter content in the leachings of the second year is probably responsible for the higher sulfur outgo. There is a higher concentration of sulfates in the leachings during the fall than at any other season of the year. This is clearly brought out in the sulfur data on the leachings of the second year.

[4] Actually these losses can not be considered as such, as will be shown presently. In reality these are the quantities which percolated through the A_1 horizon.

Sesquioxides and silica. There is no other set of compounds released in the podzol process of soil formation which characterizes the process as the sesquioxides do. They move through the profile in the colloidal state protected by the negatively charged humus compounds, as pointed out elsewhere (2). The leachings offer an opportunity to follow up the movement and translocation of the sesquioxides.

In presenting the data on the sesquioxides it is well to point out that no provisions have been made for the evaluation of the PO_4 and Ti ions which come down with them.

Considering the sesquioxides as they are, we note that their release fluctuates from year to year. With the increase in total solids during the second year there was a corresponding increase of the R_2O_3 constituents. They also show a tendency to increase in concentration in the leachings during the fall, but not in such striking manner as the other constituents do. There are other factors inherent in the nature of colloids which might control the movement of the sesquioxides. One of them is the state of aggregation of the colloids. It is known that after heavy rains the soil colloids become more highly dispersed and therefore more mobile. The mechanism of this reaction is simple: the electrolytes are removed by the rain water from the surface horizon and moved downward. The absence of the electrolytes tends to peptize the colloids, and naturally the degree of dispersion increases, as a result of which the diffusion coefficient increases. An examination of the data in tables 3 and 4 on the concentration of R_2O_3 in the leachings shows that after heavy percolation, which follow heavy rainfall, it increases. This, however, is to be noted: the data also show that usually the periods of high R_2O_3 concentration are also periods of high concentration of other constituents. Theoretically there is the possibility of retardation of the R_2O_3. A preliminary check-up has shown that the electrolytes seem to appear with the first few hundred cubic centimeters of leachings, whereas the R_2O_3 concentration begins to increase after that. More data are to be accumulated before anything more definite might be said about this phase.

There is no positive correlation between the loss on ignition (organic matter) and the sesquioxides. If anything, the data show that a larger loss on ignition corresponds to a lower sesquioxide content. This might appear as a contradiction to the prevailing idea that the sesquioxides move with the humus complexes. As a matter of fact it is not known whether an excess of humus is conducive to a higher mobility of the R_2O_3 and, perhaps, the smaller amount present was sufficient for the protective action exerted on the R_2O_3.

It is well to associate the movement and translocation of the R_2O_3 with the fundamental truth that in the circulation of the elements through the soil profile the sesquioxides do not reappear in the accumulative A_0 layer as the case is with other constituents. Plants take up little Fe and still less, if any, Al. It is the absolute loss of the eluviated R_2O_3 that is so significant in the process of podzolization. This influences the arrangement and distribution of the other soil constituents.

Closely related to the behavior of the sesquioxides is the silica. On the face of it, both exist in the leachings in colloidal state as sols and, notwithstanding their being oppositely charged electrically, they do not coagulate. From the work of Simakov (7) it would seem that since 1 mole of SiO_2 coagulates from 0.577 to 1.302 moles of Al_2O_3 or 0.290 to 0.363 moles of Fe_2O_3, the combination of the two should coagulate when the $\frac{SiO_2}{R_2O_3}$ ratio is from 1.2 to 2.3. In table 5 a few determinations on the $\frac{SiO_2}{R_2O_3}$ are reported. It shows that the ratio varies from 1.04 to 1.92, which is within the coagulation power of the SiO_2, and yet the colloids exist in the sol state. Apparently other factors such as the pH and presence of electrolytes hinder the coagulation.

TABLE 5

Silica and sesquioxides in leachings from A_1

LABORATORY NUMBER OF LEACHING	DATE OF COLLECTION	LEACHING	SiO_2 IN 100 CC.	Fe_2O_3 IN 100 CC.	Al_2O_3 IN 100 CC.	Al_2O_3 AND Fe_2O_3 IN 100 CC.	$\frac{SiO_2}{R_2O_3}$	REACTION
		liters	*moles*	*moles*	*moles*	*moles*	*molar ratio*	*pH*
	1929–30							
3	7/30	1.400	7.96×10^{-6}	0.99×10^{-6}	3.14×10^{-6}	4.13×10^{-6}	1.92	4.8
5	9/9	4.740	3.98×10^{-6}	0.496×10^{-6}	2.945×10^{-6}	3.441×10^{-6}	1.15	4.8
7	10/3	3.440	6.18×10^{-6}	1.99×10^{-6}	3.93×10^{-6}	5.92×10^{-6}	1.04	5.4
	1930–31							
17	7/23	1.300	7.62×10^{-6}	0.98×10^{-6}	3.34×10^{-6}	4.32×10^{-6}	1.76	4.8

A significant point to be noted in table 5 is the low $\frac{SiO_2}{R_2O_3}$ ratio in leaching 7 where an increase in pH occurred. This is in line with the findings of Mattson (6), who shows how the $\frac{SiO_2}{R_2O_3}$ ratio decreases as the pH increases and vice versa. More determinations on this important relationship between the sesquioxides and the silica must be made before the entire significance of it is clearly brought out.

A_2 horizon

Tables 6 and 7 present the data on the constituents that passed through a depth of 42 cm. A comparison of the quantities of constituents which leached through in the 2 years under consideration shows that the first year gave more than the second in spite of the fact that the amounts which leached through A_1 were just the reverse: during the second year more solids leached through, as shown in tables 3 and 4. This means that during the first year less of the substances which reached the A_2 horizon were retained by it, whereas more of the constituents from the second year's leachings were retained by the A_2

TABLE 6

Chemical constituents which percolated through A_2 (42 cm. from the surface) in 1929–1930

LABORATORY NUMBER OF LEACHING	DATE	LEACHINGS	TOTAL SOLIDS AT 105°C. IN		LOSS ON IGNITION			Ca IN		Mg IN		Cl IN		S IN		R_2O_3 IN		SiO_2 IN	
			100 cc.	Total leachings	100 cc.	Total leachings	Per cent	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings
		liters	*mgm.*	*mgm.*	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	1929																		
1	6/22	0.165																	
5	9/9	2.400	10.10	242.40	2.90	69.60	28.7	0.855	20.52	0.188	4.512	0.495	11.880	1.016	24.384	0.30	7.200	0.28	6.72
7	10/3	0.210	No determinations made																
11	12/20	0.090	No determinations made																
	1930																		
12	2/18	1.265										0.620	7.119	1.000	12.650				
15	6/11	1.395	8.12	113.27	3.92	54.68	48.2	0.60	8.37	0.262	3.655	0.570	7.952	1.100	15.345	0.30	4.185	0.34	4.743
Total*.....		5.525	18.22	355.67	6.82	124.28		1.455	28.89	0.450	8.167	1.685	26.951	3.116	52.379	0.60	11.385	0.62	11.463
Average per 100 cc.*....			9.11	9.37	3.41	3.27		0.7275	0.761	0.225	0.215	0.562	0.532	1.038	1.035	0.30	0.30	0.31	0.302
Calculated totals*.....			517.693		180.668			42.045		11.879		29.393		57.184		16.575		16.69	
Total per acre in grams.....			28,473.1		9,936.7			2,312.5		653.34		616.6		3,145.1		911.63		917.95	
Total per acre in pounds.....			62.71		21.88			5.1		1.43		3.56		6.9		2.01		2.02	

* For methods of calculating averages and totals, see table 3 on A_1 leachings.

TABLE 7

Chemical constituents which percolated through A_2 (42 cm. from the surface) in 1930–1931

LABORATORY NUMBER OF LEACHING	DATE	LEACHINGS	TOTAL SOLIDS AT 105°C. IN		LOSS ON IGNITION			Ca IN		Mg IN		Cl IN		S IN		R_2O_3 IN		SiO_2 IN	
			100 cc.	Total leachings	100 cc.	Total leachings	Per cent	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings	100 cc.	Total leachings
		liters	*mgm.*	*mgm.*	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	1930																		
25	12/30	1.870	10.92	204.20	3.80	71.06	34.3	1.06	19.82	0.393	7.35	1.13	21.13	1.00	18.7	0.72	13.46	0.28	5.24
	1931																		
26	2/19	1.200	7.48	89.76	2.08	24.96	27.8	0.74	8.88	0.262	3.144	0.44	5.28	1.05	12.6	0.58	6.96	0.24	2.88
27	3/9	0.250										0.60	1.50	1.10	2.75				
28	3/30	0.910	7.20	65.52	2.01	18.29	27.9	0.82	7.46	0.302	2.75	0.80	7.28	2.00	18.20			0.28	2.55
34	6/18	0.045	No determinations made																
Total*.....		4.275	25.60	359.48	7.89	114.31		2.62	36.16	0.957	13.244	2.97	35.19	5.15	52.25	1.30	20.42	0.80	10.67
Average per 100 cc.*....			8.53	9.03	2.63	2.87		0.873	0.908	0.319	0.332	0.742	0.83	1.29	1.24	0.65	0.665	0.266	0.268
Calculated totals*.....			386.03		122.69			38.82		14.19		35.48		53.01		28.43		11.46	
Total per acre in grams*.....			21,231.7		6,747.9			2,135.1		780.5		1,951.4		2,915.6		1,563.7		630.3	
Total per acre in pounds*.....			46.7		14.8			4.7		1.7		4.3		6.4		3.4		1.3	

* For methods of calculating averages and totals, see table 3 on A_1 leachings.

horizon. The significance of the rôle of the A_2 horizon in the movement and translocation of soil constituents will be more clearly brought out in the discussion following.

Total solids and loss on ignition. The increased quantity of total solids in 1929–1930 as compared with 1930–1931, corresponds to the increase in total leachings as shown in tables 6 and 7. Why A_2 percolated more in 1929–1930 than in 1930–1931, notwithstanding that less leachings from A_1 reached it, and why the reverse was true for 1930–1931 has been discussed in a previous publication. In short, it has been pointed out that the state of the colloids control the percolation rather than the total volume of rainfall or leachings.

Just as in the case of the leachings from A_1, the increased percolation also increased the concentration of the total solids—3.27 against 2.87 mgm. per 100 cc.—instead of decreasing it as one might have expected. There is, however, a distinct difference in the loss on ignition—34.8 and 31.7 per cent in A_2 and 38.6 and 45.9 per cent in A_1. This, of course, is due to the retention of organic matter in A_2. Of the total solids which reached the A_2 from A_1 only 17 per cent percolated through A_2 in 1929–1930 and 8.3 per cent in 1930–1931.

Calcium and magnesium. Of the total 19.4 pounds of Ca which reached the A_2 horizon from A_1 during the first year, only 5.1 pounds percolated, i.e. only 26.2 per cent was lost, if we consider the substances that pass a depth of 42 cm. (about 16 inches) as such. During the second year of a total of 23.8 pounds 4.7 pounds, or 20 per cent, percolated. It is of interest to note that whereas the total solids were 34.7 per cent higher in the leachings of the first year when of the second there was only 8.5 per cent more Ca. The Mg content was even lower, and the same was true for the Cl and R_2O_3. This again points to the fact that the increase in total solids was due primarily to the organic matter.

A comparison of the concentration of Ca per 100 cc. of the leachings in A_1 and A_2 for the corresponding leaching numbers shows that in 1929–1930 (see leachings 5 and 15) it increased in A_2. A similar tendency is to be noted in 1930–1931 (see leachings 25 and 28). Unfortunately there are not on hand many more determinations which might throw more light on the movement of this all-important cation. But as it stands, we might conclude that there is a tendency for the increased quantities of Ca in A_2 to leach away. One must not forget that it is this horizon which serves as the feeding grounds for the forest vegetation, and how much of the mineral substances are taken out in this manner is not definitely known.

Chlorine and sulfur. The inconsistency noted in the Cl content of the A_1 leachings is also true for the A_2 leachings. In 1929–1930 more than 37 per cent and in 1930–1931 more than 30 per cent leached away. From these data it seems that a considerable amount of Cl remains behind in A_2. How much of it is used up by the forest vegetation to go again into circulation is not known.

Large quantities of sulfur remain behind in A_2, but a good portion of it is used up by the forest vegetation to be brought again into circulation.

Sesquioxides and silica. In mature podzols the A_2 is characterized by its low R_2O_3 content. Thus in following up the process of podzolization—as this could be done in the lysimeter studies reported—one should expect a high outgo of R_2O_3 from A_2. From the meager data on hand for the 2 years this is not substantiated to any appreciable extent. There is an indication that the concentration of R_2O_3 does increase in the leachings of the A_2 horizon. As the data stand, it would seem that the soil under consideration is only slowly podzolized. Morphological and chemical evidences to this effect are on hand and will be published in some other connection.

Nothing definite may be said about the SiO_2. The difficulty in measuring such small quantities of SiO_2 makes small numbers of determination rather doubtful, and the few leachings obtained from A_2 did not permit any larger number of determinations to be made.

GENERAL DISCUSSION

In the foregoing pages an attempt has been made to account for the constituents which move through the soil profile from the A_1 horizon to A_2 and from there to the B horizon. Nothing has been said about the upward movement of the various constituents by the forces of capillarity. It is possible that some of the obscure results might find an explanation just in this upward movement, which takes place especially through A_2 toward the bottom part of A_1. This point needs to be investigated.

An important point to be kept in mind in connection with the analyses presented is that the quantitative aspect of the data hinges on the assumption that the direction of the leachings through the horizon of eluviation is vertical. In the first paper of this series (3) on the percolation of moisture through the soil profile evidence has been presented to justify this postulate. It has been pointed out that in the open, practically structureless A horizon there are no obstructions for the water to move in a vertical direction. Only when the moisture reaches the compacted B horizon it begins to diverge from its vertical course and begins to move also in a horizontal direction following hollow root paths, cracks, and burrows of animals and insects.

The 2 years for which data are available were rather abnormal with respect to rainfall. It was below normal: 10 inches in 1929–1930 and 13.12 inches in 1930–1931. Perhaps this rainfall shortage is responsible for the shallow percolation. Under normal rainfall conditions we may get a deeper penetration. This remains to be seen. The fact is that the leachings from B and C are erratic and scant and because of that, very few determinations are available. As a matter of fact the data on hand seem to indicate that most of the constituents which passed the A_2 horizon were retained by the B horizon. Only 1 per cent of the leachings passed through the B horizon and about 2 per cent through the C. Thus a very small proportion of the constituents from the soil under consideration went to the ground waters during the 2 years.

The foregoing discussion invites a comparison of the removal of constituents

as shown by the new type of lysimeters and that of the old one. The Cornell lysimeter data (4, 5) offer detailed figures, and in table 8 a summary has been made. Since no means are available at present to trace the exact movement of the constituents after they pass the A_2 horizon the figures on this horizon are given in table 8 beside the Cornell data.

The remarkably wide differences in the removal of constituents from the soil as shown by the two methods—old type and new type of lysimeters—make one wonder whether the results are reliable. A closer analysis of the data reveals some interesting facts of importance in soil fertility studies and soil in general, to the end of which lysimeter equipments must serve.

According to the figures of Lyon and Bizzell (4) the weight of dry soil—which makes up the first foot in the lysimeters—per acre foot is 3,645,000

TABLE 8

Average annual removal of various constituents from the soil, as indicated by the Cornell and New Jersey lysimeters

(In pounds per acre)

CONSTITUENTS	FROM CROPPED TANKS* BY:			FROM UNCROPPED TANK	FROM THE NEW JERSEY LYSIMETERS
	Drainage	Crop	Total	Drainage	Drainage†
	pounds	*pounds*	*pounds*	*pounds*	*pounds*
Total solids	955.0	?	955.0	2,223.9	54.7
Ca	177.1	13.2	190.3	364.0	4.9
Mg	33.8	7.4	41.2	60.2	1.6
S	35.5	10.4	45.9	44.0	6.7
SiO_2	32.4	?	32.4	48.6	1.66

* The data presented are for the first 5 years (the same is true for the 15-year period) on the cropped tanks 3, 5, and 6 and on the uncropped tank 4. All tanks received two manure applications at the rate of 10 tons per acre during the period. Compiled from N. Y. (Cornell) Agr. Exp. Sta. Mem. 12 (4).

† Based on the leachings from the A_2 horizon; average of 2 years.

pounds with a 0.34 per cent CaO content, which gives a total of CaO equal to 12,393 pounds. An acre foot of dry soil which makes up the second foot in the lysimeters weighs 3,827,500 pounds with a 0.28 per cent of CaO, which gives a total of 10,717 pounds of CaO. An acre foot of dry soil which makes up the third foot in the lysimeters weighs 3,999,500 pounds with a 0.49 per cent CaO content, which gives a total of 19,597.5 pounds of CaO. An acre foot of dry soil which makes up the fourth foot of the lysimeters weighs 3,710,000 pounds with a 1.53 per cent CaO content, which gives a total of 56,763 pounds of CaO. Thus 4 acre feet of soil contain a total of 99,470.5 pounds of CaO or 71,050 pounds of Ca. Besides that, 80 pounds of Ca is added once in 4 years in the form of manure, or 20 pounds per year. On the debit side, we have 190.3 pounds of Ca removed yearly. If we subtract from it the yearly addition of

20 pounds we have a net loss of about 170 pounds of Ca per year. Now, if we divide the soil's Ca assets—71,050 by 170 we get the figure 418, which means that in 418 years not a trace of Ca will remain in a column of soil 4 feet deep. The figure given is for the cropped lysimeter tank. If we take the losses from the uncropped tank and calculate as above it would show that in 206 years no lime would remain.

Let us make another calculation. Of the 2,223.9 pounds of total solids lost from the uncropped tank about one-fourth is probably organic matter, which means that 1,717 pounds constitute the mineral portion. Now the weight of the 4 acre feet column of soil is 15,175,000 pounds. Disregarding the organic matter in it and dividing 15,175,000 by 1,717 we obtain the impressive figure of 8,830 years. In other words after this period of time there would be nothing left in the lysimeter tank, or the surrounding landscape would sink 4 feet. Of course, the author is mindful of the absurdity of such a possibility. This could only happen if the proportion of the constituents in the total solids were equal to that in the soil, which is not the case. It is given simply as a curiosity which perhaps should not find a place in a scientific paper.

But let us return to the Ca removal, the calculations of which will stand the mathematical test, except that actually the Ca outgo will undoubtedly slow down because of the inherent property of soil material to form a soil body, which means a differentiation into horizons with the consequent formation of a B horizon which will prevent the washing out of soil constituents and hence prevent the destruction of the soil.

Without further analysis of the impossibility of the losses as reported by the Cornell lysimeter studies the author is inclined to believe that the removal of the constituents from the soil body as indicated by the new type of lysimeters is closer to actual natural conditions. The calculations perhaps lack precision, but they are based on reasonable grounds and are probably not far wrong.

There is this to be remembered: the data presented are based on leachings from forest soils. How much of the inferences will hold true for cultivated soils is, of course, problematic. Another set of this type of lysimeters in cultivated soils would clinch the problem of the movement of soil constituents and its relation to soil fertility—the ultimate aim of our studies.

In our soil fertility practices we strive to maintain the favorable balance of soil constituents—a state naturally maintained in the forests. A knowledge of the conditions in the virgin soils is the fundamental preamble for the methods which shall be profitably applied when the human being enters as a possible factor in the processes of soil formation, i.e., when cultivation begins. Thus far we have attempted to gain knowledge from empirical experimentation without consulting the actual conditions in the natural soil. After all, we cultivate only 6 inches deep and although this has undoubtedly a marked influence on the remaining larger portion of the soil body the tendencies noted in an undisturbed soil will probably hold true, and especially for the rest of the soil body below the plowed layer. There might be some difference in the degree

of these tendencies but generally they will probably remain true. The data presented are therefore of significance and with the evaluation of the variable conditions existing between cultivated and virgin soils they can be used for comparison with data obtained empirically to show the loopholes existing in our old methods.

SUMMARY

Data on the conductivity and reaction of leachings from the new type of lysimeters at the New Jersey station for a period of 2 years show that during the fall there is an increase in concentration of basic salts in the A_1 horizon. This influences the conductivity—a rise during October and November. A similar rise is noted in the pH. There is a definite parallelism between the rise in conductivity and the increase in pH.

There is an increase in the total quantity of total solids in the leaching of the second year in A_1. This is accompanied with a rise in concentration of the solids. The increase in total solid is primarily of an organic nature.

The alkaline earth bases—Ca and Mg in A_1—show a tendency to increase in concentration toward the end of the summer and fall, attaining a maximum in October and November.

The chlorine content of the leachings shows no consistent behavior. Apparently the direction of the winds and the Cl content of the rains govern the quantity of this ion. The S content is fairly high and it is suggested that the rapid oxidation of the organic sulfur compounds is responsible for augmentation of sulfates in the leachings.

The R_2O_3 also increased in concentration during the second year, but not so much as the other mineral constituents. A discussion is presented on the relation of the removal of R_2O_3 to organic matter and mineral substances. The SiO_2 movement follows the R_2O_3 and the $\frac{SiO_2}{R_2O_3}$ ratio varies from 1.04 to 1.92. The low ratio corresponds to an increase in pH which is in line with the findings of Mattson (6).

Of the total solids which reached A_2 from A_1 only 17 per cent percolated through A_2 during the first year and 8.3 per cent during the second year. There is lower loss on ignition in the total solids from A_2 than from A_1 indicating a retention of organic matter in A_2.

The concentration of the mineral constituents—Ca, Mg, Cl, S, and R_2O_3—increased as a rule in the leachings of A_2 as compared with A_1.

A comparison of the constituents removed in the leachings through A_2 with those removed from the Cornell lysimeters shows that from 20 to 40 times as much, depending on the constituent, was removed from the Cornell lysimeters. Calculations made on the assets and outgo of Ca from the soil of the Cornell lysimeters show the improbability of such losses under natural conditions. The abnormal condition of the soil material in the lysimeter tanks is responsible

for such striking losses. It is inferred that the old type of lysimeters is not suitable for full orientation as to what is actually going on in the soil.

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